Educational experiences as fields of influence in physics: An exploration of the critical incidents in student education.

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STATEMENT

I hereby declare that this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

Signature: ....

Abstract

The purpose of this thesis is to explore the field of influences on the occupational trajectories of physics graduates in the United Kingdom. My research examines the assumptions by government and policy makers that school education holds the key to providing more physicists available for employment in physics-related occupations. The research analyses qualitative data from current and recently graduated students to explore the field of influences on their decisions to take physics, and how these experiences influence their identity as a scientist. My hypothesis tests these assumptions by examining the significant events, or critical incidents, during the educational experience on a physics degree.

The research design is a case study of the physics departments of two UK institutions. A series of interviews provides insight into the educational journeys of current and recently graduated physics students and the consequent analysis identifies emergent themes. These themes include how the influences of school education and social and individual expectations engage people into enrolling on a physics degree. Further analysis explores how events occurring on the degree courses may influence occupational trajectories. My findings identify attitudes to laboratory work and institutional feedback as significant influences to this sample of individuals during their degree experience. This work has implications for highlighting the significance of laboratory work in future science education policies, as well as contributing to the extant research on STEM education.

Acknowledgements

Throughout my own journey on completing this thesis, I have been surrounded by people who have propped me up, cajoled and encouraged me along the way. I would like to take this opportunity to thank my supervisors, Professor Colleen McLaughlin and Doctor Andrew Chandler-Grevatt for not only their patience with me but also their needle-sharp questions, which allowed me to fine-point my focus. I would also like to thank my parents for their dedication in transcribing my interviews and for their commitment to learning all kinds of scientific, technical language along the way. My thanks also go to the undergraduates, graduates and staff at the two institutions who not only gave up their time, but also allowed me access to their past and present thoughts on their educational journeys during interviews. My thanks also go to friends and colleagues at Davison CE High School for their support and helpful emails about relevant items in the news, and to the previous Head Teacher for contributing to my fees. I have to acknowledge my stepsons: Adam, Angus, Archie and Alfie, for coping with other people cooking all those days when I was being re-educated at university and away interviewing. Most of all, I would like to thank Keith, Ellie and Sam for encouraging me, feeding and watering me, and believing in me right to the end.

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"But then once you go through your degree, you learn the truth about all these fancy things you've heard of. You realise they aren't quite as exciting, at least in a general sense. But then you look at the theory and you say - is this really exciting? And it really is exciting, but you have to do all this work to understand why, without all the hyperbole."

(A2CCF, female physics PhD student, 2014)

INTRODUCTION

As part of my Doctorate in Education, I completed a Critical Analytical Study (CAS) examining the mismatch between school science and authentic science (Holmes, 2013). My CAS suggested to me that during secondary school, science lessons might create unrealistic expectations about the nature of real life scientific methodology. There is currently much investment into encouraging a greater uptake into further and higher science education (Department for Education, 2011a). This investment implies that policy makers believe more STEM[1] entrants at higher education will alleviate the STEM shortfall in the workforce (Department for Innovation, Universities and Skills, 2008). My research focuses on this assumption and examines a small part of why, as this investment targets STEM education to increase numbers of STEM trained individuals, the deficit in the STEM workforce remains. The area of STEM is a large one, and so this study focuses only on science, and where possible, the smaller subcategory of physics.

There is evidence that post-graduation, many undergraduate physics students seek employment in alternative areas to their subject area studied (Institute of Physics, 2010). In Figure 1 (overleaf), the data illustrates that 58%[2] of physics graduates were in occupations[3] hardly related to their degree (Institute of Physics, 2010):

[1] STEM (Science, Technology, Engineering, and Mathematics).
[2] This data is based on a sample of 502 questionnaire respondents. The study aimed to track career development of physicists and provided only quantitative data with no context given for career choices.
[3] The data for this study was gathered from final year physics students between 2006-2010, thus these occupations refer to physics graduates between 4 and 1 year after graduation. No details were given in the survey as to whether this was their first job.

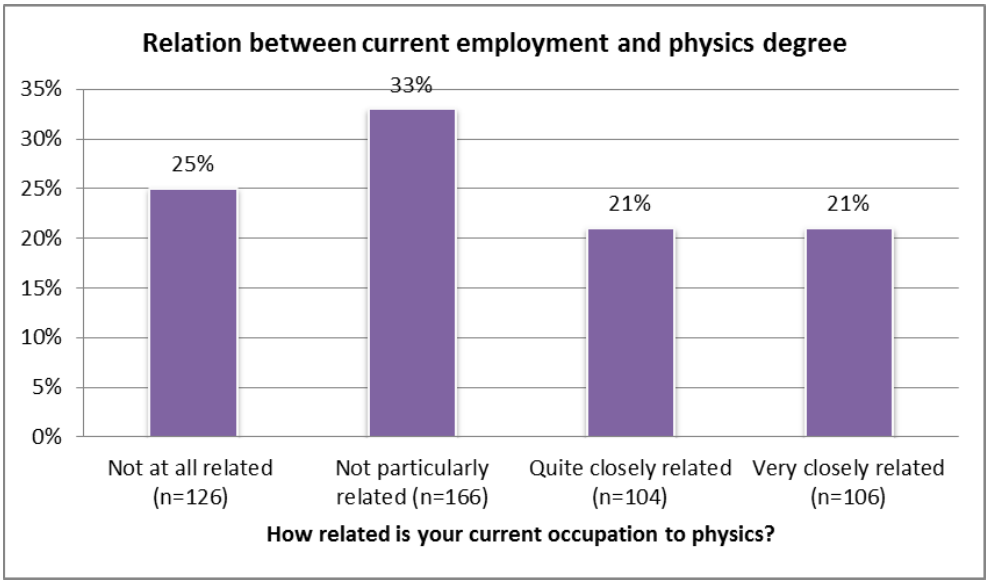

Figure 1: Relation between current employment and physics degree (Graph generated using data from the Institute of Physics, 2010)

This percentage of physics graduates not working in their specialist field seems to challenge the argument that there is a shortage of physics specialists available for the labour market (European Commission, 2004; Confederation of British Industry (CBI), 2010). This shortfall of workers is supposed to number in the millions across the globe (Charette, 2013) and predicted to increase. A recent report (Bureau of Labour Statistics, 2012) stated that over the next decade, one million additional STEM graduates were required in North America; in the UK, a report by Harrison (Royal Academy of Engineering, 2012) stated the need for 100 000 STEM graduates annually until 2020 to supply market demands. In Chapter 1, I will explore the evidence for this deficit in the STEM workforce more closely, as well as the investment and policy amendments in secondary and tertiary education that aim to increase its uptake.

I understand that the problem of why physicists do not continue to practice their subject is a convoluted one, which involves interest (Brickhouse *et al*, 2000), parental background (Van deWerfhorst *et al*, 2003), school education (Aschbacher *et al,* 2010), financial security (Chevalier, 2011), gender (Hazari *et al*, 2010), as well as many other factors. I also understand that a university education is not an instrumental form of education, in that it does not exist only to produce a workforce. However, as noted by the OECD in 2007 “the local availability of knowledge and skills is becoming increasingly important…As key sources of knowledge and innovation, higher education institutions can be central to this process" (p. 11). Similarly, a report by Bloom et al (2006) states that

> Knowledge-based competition within a globalizing economy is prompting a fresh consideration of the role of higher education in development and growth. Previously it was often viewed as an expensive and inefficient public service that largely benefited the wealthy and privileged. Now it is understood to make a necessary contribution, in concert with other factors, to the success of national efforts to boost productivity, competitiveness and economic growth. (p. 1)

Studies also indicate a need for STEM participation policies to make science a 'thinkable' career option to diversify the individuals entering the labour market (Archer *et al* 2012). These factors will be explored in Chapter 2, where factors influencing decisions to enter higher education are examined. These will be examined in relation to how a science identity is created and maintained, providing the foundations for my qualitative data analysis.

My research examines the final stages of education, where people have made the decision to remain in physics education. I will examine only one small subsection of the many factors that may influence occupational decisions; the educational experiences occurring during an undergraduate physics degree course. In Chapter 3, I will outline my research methodology and why I have chosen to use a case study to examine physics undergraduates and graduates. In Chapter 4, I discuss the themes that emerge from educational events discussed during the interviews. I will endeavour to use these events to explore how the respondents feel about physics before and during[4] their degree, and whether these events have any influence on their anticipated occupational decisions.

As a teacher of physics who undertakes to encourage and motivate pupils to continue their studies to higher levels and physics-related occupations, experiences on a physics degree course influencing expectations and destinations of students are a

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[4] And after their degree course for those who have graduated.

small but important contribution to understanding the STEM workforce deficit. The analysis of experiences on physics courses may help me find out whether educational experiences are significant influences on the occupational decisions of graduate physicists. In this respect, I am hope my research will contribute original knowledge about the educational journeys of physics graduates to the broader pool of research on STEM subjects.

In the next section, I will examine evidence for the perceived shortfall in the science workforce, and the influence of investment and policy amendments in science uptake and STEM occupations.

CHAPTER 1 THE POLICY CONTEXT

Science is considered one source of economic progress, in that it introduces new ways of thinking about our place in the world (OECD, 2007). The International Council of Scientific Unions highlights the importance of science in society by encouraging educators to:

> [D]emonstrate to the world that having the capacity to understand and use science is economically, socially, and culturally profitable. Indeed, the very habitability of the planet will depend on global popular consensus. As such, the spread of scientific culture, of scientific ways of thinking, and of knowledge is tied to the fate of humanity.
>
> (1996, p. 1)

During my experience as a science teacher, I have participated in various initiatives to encourage and increase the uptake of physics to higher education and yet there remains a plateau[5] in A' level physics entries (Truss & DfE, 2013). Within science education, my role is to develop the skills and potential for the next generation of scientists; to motivate and encourage schoolchildren into exploring potential futures in scientific careers and to encourage a percentage of students today to become the scientists of tomorrow.

My research for this thesis has covered a broad range of subjects surrounding education and occupational choice. My examination of the literature has included societal and political ideas about the global shortage in science graduates. Although a more detailed examination of the evidence is discussed later on in this chapter, the literature indicates that numbers of science graduates are decreasing, while emphasising an inevitable economic decline. From my position within education, I have professional concerns that the initiatives in education, introduced to increase numbers of qualified scientists, have not reduced demands from industry for science graduates. In fact, there is some evidence to suggest that although there has been an increase in the numbers of people obtaining science degrees, there remains

[5] The data for this plateau is examined on page 50

dissatisfaction by employers about the diminishing graduate numbers available for employment (Main, 2012).

There are various reports from a range of different countries to suggest that an increase in numbers of science professionals would support economic development (European Commission, 2004; Committee on Science, Engineering and Public Policy, 2005; OECD, 1994). The OECD highlighted more recently that

> Innovation is a major driver of productivity and economic growth, science, technology, innovation and entrepreneurship …are important mechanisms for encouraging sustainable growth (2013, p. 15).

The raising of achievement in science education is thus considered to be a prerequisite of economic progress. The UK science industries are recognised as vital to the overall UK economy, with a turnover of approximately £257 billion (ONS Annual Business Inquiry, 2007 cited in CBI, 2010). The policy discourse on science education has indicated that raising standards would increase the economic potential of the United Kingdom (CBI, 2010; Higher Education Funding Council for England, 2008; Institute of Physics, 2003).

1.1 Definitions of key terms in STEM

The term STEM (Science, Technology, Engineering and Mathematics) is increasingly used, but remains open to many differing interpretations. The Government response to a report on Higher Education in STEM acknowledged that there was much confusion in this area, arguing that each interpretation was deemed necessary by different organisations (House of Commons, 2010). They suggest the definition of STEM as used by the Department for Business, Innovation and Skills (BIS), based on JACS[6] coding is the most practical. As a subject of higher education, the definition of STEM using JACS codes the following broad subject groups:

[6] Joint Academic Coding System is the subject classification system used by HESA and UCAS

(B) Subjects allied to medicine

(C) Biological sciences

(D) Agriculture & related subjects

(F) Physical sciences

(G) Mathematical sciences

(G) Computer science

(H, J) Engineering & technology

(K) Architecture, building & planning

Thus, a graduate in any subject group above is considered a STEM graduate[7]. I intend to use the JACS system as it remains a consistent categorisation (House of Commons, 2010). As I am exploring the experiences of physics students, I will narrow the field to use the JACS 3 coding of physical Sciences (F); however, this includes chemistry and related subjects: as I am specifically interested in physics, I will focus on degrees coded for physics (F300[i]):

> The study of the properties of matter and energy and the relationships between them, making extensive use of mathematical techniques and models.
>
> (Higher Education Statistics Agency, 2013)

It must be added, however that the IOP widens this definition to include the "asking of fundamental questions and using observation and experimentation to find answers" (IOP Physics.org, 2012).

My study is on what educational experiences may influence the destinations of student physicists so a definition is required to clarify the areas of employment where STEM graduates and specifically physicists are required (UK Shortage Occupations List, 2015). The *STEM Graduates in non-STEM jobs* report (Department for Business, Innovation & Skills, 2011) describes categories of occupation where a degree level

[7] Medicine, dentistry and veterinary science are deliberately excluded, because these graduates predominantly enter the related STEM occupations (e.g. doctors, dentists, vets and nurses) and so remain within a separate section of coding.

training in STEM[8] is considered a necessary prerequisite. This is further refined by the Institute of Physics report (2012) which highlights a subsection of the Standard Industrial Classification (SIC)[9] as used by the ONS. These are outlined in Appendix H IoP definition of physics based sectors and are defined by the IOP as “those sectors where the use of physics is critical to the survival” (2012, p. 35).

Many STEM graduates have occupations in professional and managerial occupations, and as indicated in Figure 2, the vast majority of people working in STEM occupations, or those involving STEM skills, have either no STEM higher education or no higher education at all. I have included this data to illustrate that many jobs considered by JACS3 to be STEM do not necessarily require a STEM qualification; instead, they rely upon the skills acquired ‘on the job’.

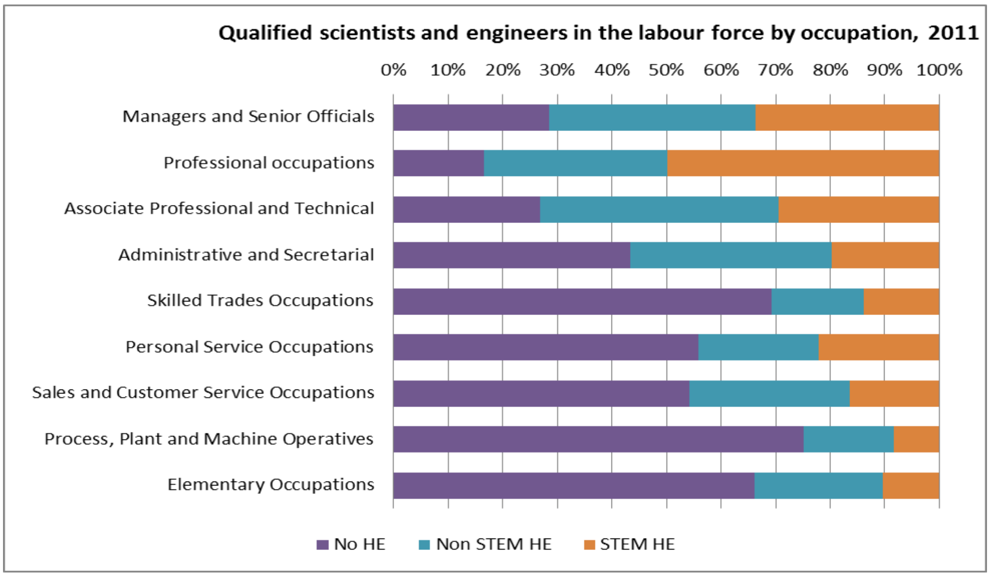

Figure 2: Qualified scientists and engineers in the labour force by occupation, 2011

IN MY RESEARCH HOWEVER, I WILL EXAMINE THE OCCUPATIONS OF GRADUATE PHYSICISTS IN RELATION TO THE PHYSICS-BASED SECTORS (INSTITUTE OF PHYSICS, 2012) AND WILL NOT INCLUDE STEM-RELATED JOBS, SUCH AS PROFESSIONALS IN STEM SPECIALIST BUSINESSES OR THOSE UNRELATED TO STEM. THE

[8] STEM Core jobs include those where STEM degree disciplines are closely related to the type of work; for example, scientific, research and development professionals, engineering and IT professionals and a range of other associate scientific professional and technical jobs (such as lab technicians, surveyors, ophthalmic opticians etc.)

[9] The standard industrial classification (SIC) is used in the UK for classifying business establishments by the type of economic activity in which they were engaged.

IOP REPORT STATES, "THERE MAY BE MANY PHYSICS GRADUATES IN THE PROFESSIONAL SERVICES SECTOR, BUT [BECAUSE THEY DO NOT MAKE DIRECT USE OF PHYSICS] THIS SECTOR WOULD NOT BE CLASSED AS PHYSICS-BASED." (2012, P. 15).

I intend to leave the discussion of my research methodology until after I have provided a context to the area of study and the reasoning for my research in the following sections.

1.2 THE STRATEGIC IMPORTANCE OF SCIENCE

In the report *A Vision for Science and Society* (Department for Innovation, Universities and Skills, 2008), Lord Drayson, then the Minister of State for Science and Innovation asked the question "What do we mean by science?" The answer presents a much broader image of science than that reflected in the statutory subject-based national curriculum governing the work of schools in England:

> [W]e mean all-encompassing knowledge based on scholarship and research undertaken in the physical, biological, engineering, medical, natural and social science disciplines, including the arts and humanities, which is underpinned by methodologies that build up and test increased understanding about our world and beyond. (p. 4)

The need for a science education is widely accepted across the world as an important part of the curriculum (UNESCO; ICSU, 1999). The English National Curriculum currently consists of compulsory core subjects: English, Mathematics and Science in Key Stages 1 - 4 (Department for Education, 2011d). The case for giving science a central role in the UK school curriculum has been made almost continuously over the past century. One argument is based on the economic and strategic importance of science (CBI, 2010), which wants the education system to provide a steady flow of students into jobs requiring advanced scientific knowledge and expertise (BIS, 2014). This requires that schools offer a science programme that provides the early stages of training in science:

> High quality exposure to STEM subjects must start at primary school and the options and opportunities should become increasingly 'tailored' at secondary school and

> through skills training, further and higher education. (BIS, 2014, p. 23)

A popular perception of STEM in the UK, and in many other countries, is of a discipline in crisis: “fewer young people enrol in science, technology, engineering and mathematics (STEM) subjects at university” (BBC online, 2007); there is a “lack of specialist teachers to answer the awkward, supplementary questions of enquiring minds”, (Smith, 2008, p. 21); “the cost to the economy of the ‘swing’ from the sciences is estimated in billions of pounds” (The Times, 2008, p. 9). Yet, with society in a constant flux with the process of globalisation and information exchange, modern society is labelled with terms that hint at the defining roles of science and technology: the post-industrialist society; the information society; the knowledge society. This latter term seems to be founded on the belief that science and innovation lead economic and social development, “influenc[ing] people's daily lives to the extent that some scholars have come to view science as the main defining characteristic of contemporary societies” (Thorlindsson & Vilhjalmsson, 2003, p. 100).

The economic argument suggests that for stability, economic inputs, such as materials, labour and capital, must be in equilibrium with output (Christ, 1952). In such models, productivity growth is only dependent on the rate of technological progress. This growth comes from research and application of higher skills, most frequently found in STEM occupations (UKCES, 2011). Scientific research has been increasingly commodified in contemporary society with greater interdependence between science and industry, as industrial processes become more technologically advanced (Etzkowitz, 1998; Ziman, 2000). A cynic would suggest that the reason behind the cry to push more people into science degrees is motivated by politics and economics; there are benefits for both in having more qualified scientists. In stretching the arguments for innovation and societal development, it would mean that a society with greater numbers of scientists would have a greater global authority. The Department for Education (DfE) hints at this ‘added value’ workforce:

> It is essential to invest in STEM education and skills at all levels to create the highly skilled workforce that will be essential to a high added-value economy and UK competitiveness (The Science Council, 2010, p. 1).

An Institute of Physics report (2012) also highlights the economic impact of physics through science (educators and researchers), businesses (employees with technical expertise), and through technologies by applied physics (e.g. in healthcare). An Institute of Physics report (2007) found that UK physics based industries were responsible for 62% of the total manufacturing output in 2005, and although UK manufacturing fell by 10% between 1992 and 2003, the numbers employed in physics-related industries remained constant. Prior to 2008, physics-based sectors had greater employment numbers compared with the rest of the economy; however, following the financial crisis, this was reversed, with number of jobs falling greatly in physics areas (Institute of Physics, 2012). The IOP suggests that the manufacturing sectors were particularly affected by the economic downturn (Institute of Physics, 2012, p. 11). As a proportion of the total however, the absolute number of physics jobs has been declining since 2008, although demand for employees in physics sectors other than manufacturing (i.e. transport, electricity and defence activities) has increased (Institute of Physics, 2012).

1.3 THE EVIDENCE FOR A SHORTFALL OF SCIENTISTS

Over the last twenty years, there have been numerous reports commenting on the shortfall of specialist physical scientists (Confederation of British Industry (CBI), 2010; HEFCE, 2008; Osbourne & Dillon, 2008; The Royal Society, 2008; Melville, 2007). Although my focus remains in the UK, there is evidence that this shortfall is international. In Australia, research highlights a “continuing growth in the biological science university enrolments whilst physics and chemistry decline” (Sharma *et al*, 2009, pp. 67-8). Studies completed in Canada (Orpwood, Schmidt, & Hu, 2012) and America (Heuer, Einaudi, & Kang, 2014) also note a similar decline in science graduates. In Europe, following an international conference in Brussels (*Europe Needs More Scientists*), a dedicated committee was set up with aims of “increasing the number of research personnel and science professionals in Europe” (European Commission, 2004b, p. 2). The Nuffield Foundation also highlighted that “science is an important component of our European cultural heritage” but indicates, “in recent times fewer young people seem to be interested in science and technical subjects" (Osbourne & Dillon, 2008, p. 5).

In their study on how experiences shape perceptions of science ability and thereby trajectories, Aschbacher *et al* (2010) fear that "science understanding is an increasingly precious resource throughout the world" (p. 564). Buerhaus *et al* (2007) emphasise concerns about shortages of both scientifically skilled employees and future research scientists. Equally, the CBI (2010) highlights the dangers of failing to overcome the shortfall in qualified scientists:

> Science, engineering and technology are the foundation for innovation and technological advance, and are traditional strengths of the UK economy. But skills shortages will threaten businesses capacity for growth unless action is taken now.
>
> (Confederation of British Industry (CBI), 2010, p. 3).

Within this report, there is concern that the growth in STEM industries forecasts the need for 600,000 professionally skilled scientists by 2017; a 40% increase in STEM graduates is estimated in order to meet this demand. Organisations continuously stress the need for increasing numbers of qualified physics and graduates. A study considered in a leading education newspaper reinforced this perception of a national crisis in physics: "Today's report says that A' level physics entries fell 49.5% between 1982 and 2005, from 55 728 to 28 119. Meanwhile, the proportion of 16-year-olds studying A' level physics fell from 6% in 1990 to 3.8% in 2004" (Paton, 2006). More recent evidence, however, has noted that numbers of physics A 'levels rose from 29 436 in 2009 to 32 860 in 2011, after falling continuously between 1999 and 2006 (Education Standards Analysis and Reseach Division, 2011). The significance of these figures is examined in section 1.5, where I look at the quantitative evidence that contextualises my research in physics occupation. Firstly, however, I will clarify some problems I encountered when searching for quantitative evidence on physics education.

1.4 A NOTE ON THE DATA SOURCES

Research has examined student persistence and the leakage out of 'the science pipeline'[10] occurring during education (e.g. Maltese & Tai, 2011). Qualitative studies have also explored the experiences of individual students, examining the processes underlying student persistence (e.g. Seymour & Hewitt, 1997). This data[11] is valuable in that it provides a broader picture of the progression through education. As Eisenhardt (1989) notes, my qualitative findings will be helped if there is quantitative evidence that supports it, broadening my viewpoint and helping to contextualise my research.

A problem I encountered in exploring destination data was the minefield of different sources. For consistency, I used datasets from UNISTATS[12] and HESA for A' level numbers and degree applications, as these were sources that were easily accessible to be and referred to in some of the reports I examined (Exley, 2014a; Institute of Physics, 2012). There is evidence that A 'level physics entrants increased between 2006 and 2010 (National STEM centre, 2010; Education Standards Analysis and Reseach Division, 2011). I explored GCSE and GCE A' level data from both the JCQ (2013) and DfE (2012a), hoping to track an individual cohort through their educational journey. I was unable to access this data, which would have allowed me to track the cohort from secondary to higher education by subjects taken[13]. Other studies (e.g. Main, 2012), and data from the Higher Education Statistics Agency (HESA), indicate the patterns in examinations taken; however these do not specify the examination pathway of individual students prior to enrolling on university degree courses.

A further difficulty encountered with the secondary sourced data was identifying those leaving the UK after various stages of education. A recent HESA analysis of leaver destinations indicated around 2% of the total physical science graduate population take up overseas work (Higher Education Statistics Agency,

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[10] The pipeline refers to the educational progression of students as they travel through the school system towards STEM-related careers. Subject choice and attainment will largely determine if they remain in the pipeline or if they are 'lost' from the pipeline (i.e. 'pipeline leakage') (Berryman, 1983).

[11] It is important to define my use of the term data throughout this section. In the main, I am using it as defined by the Oxford English Dictionary (2012), as 'facts and statistics collected together for reference or analyses'.

[12] UNISTATS is used for the short-term data, as there have been significant changes in the background of degree applications: for example, university fees.

[13] My status as a 'stand-alone' researcher, i.e. conducting research outside of the security of a university campus, meant that I was unable to qualify for access to relevant datasets from the UK Data service and ONS.

2014b), with destinations including paid and voluntary work in non-specified sectors. I also noted that 5% of leaver destinations remained unknown, so these too may influence the overseas total. With these limitations in mind, I decided to focus only on institutions and physics students based in England.

In Chapter 2, I examine the GCSE, A 'level, university and destination data of graduates, also using data from the Institute of Physics[14] and the Higher Education Statistics Agency[15] as I found these easily accessible. As much as possible, I utilise the most current available data.

I am acutely aware that changes in the fee-paying status of higher education and the recent economic crisis means that the most recent data comes from an unusual economic position. There has been some suggestion that university fees may have led to more demanding students (as customers), and fewer failures to complete courses due to the economic investment in the degree (Duncan, 2015). There is also anecdotal evidence that University policies are being amended in light of the challenges posed by paying students. In a recent analyses on the impact of fees, the Institute of Physics[16] found that women, ethnic minorities and lower social grades were "slightly more likely to take action to mitigate higher fees by choosing a subject that promises higher graduate salaries or higher lifetime earnings, or choosing a more applied/vocational subject" (2013, p. 4). Thus, when I examine the occupational data in the following section, I am aware that trends in uptake of STEM subjects and occupation may fluctuate in the next few years.

1.5 A DECLINE IN LABOUR OR A DECLINE IN GRADUATES

There is some evidence to suggest that science graduate numbers are not declining to the extent made out by policy makers. In 2007, Lowell and Salzman assessed how the population of American science graduates was changing. They were

[14] Statistical Report: Degree-Course Destinations http://www.iop.org/publications/iop/2012/page_55899.html, Institute of Physics, 2010. This IOP analysis also used HESA data.
[15] Destinations of leavers, https://www.hesa.ac.uk/stats-dlhe, Higher Education Statistics Agency, 2014.
[16] Fieldwork for this research was conducted by YouthSight on 1–6 March 2010. The sample consisted of 1024 interviews with students at 119 Higher Education (HE) institutions representative of the UK HE population in terms of gender, year group and university type.

concerned that the highlighted labour shortage was anecdotal and was unsupported by data. They noted that, although the proportion of science students pursuing degrees remained stable, an increase in university students meant that there were proportionally more science graduates (Lowell & Salzman, 2007). There is further evidence that contradicts this idea of declining numbers of science graduates, with Smith (2010) suggesting that many science graduates are choosing to enter other fields. Within the UK, data from HESA (2011) raises questions as to why there is the perception of decline as the total numbers of physical science students between 2007 and 2011 has increased (see Figure 3):

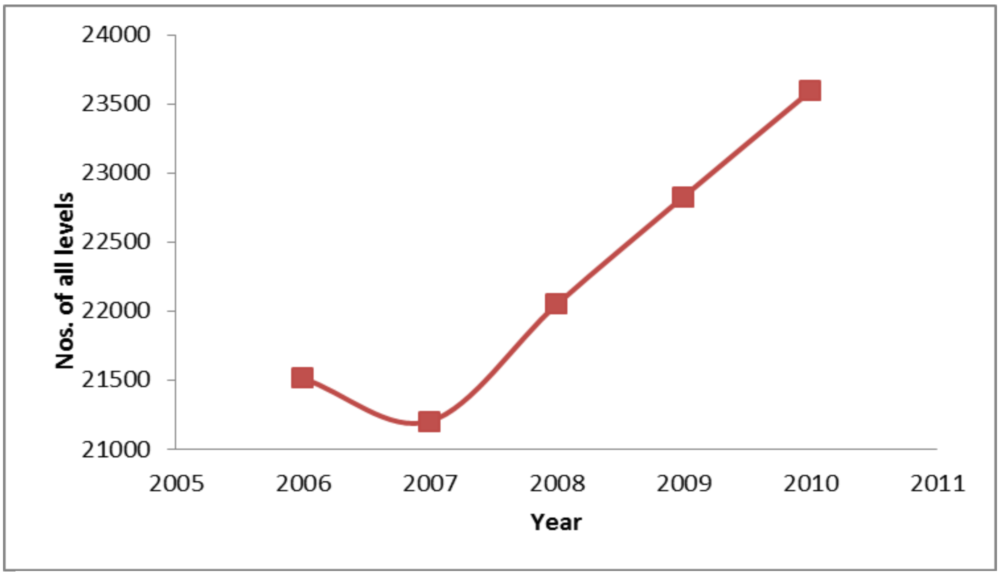

Figure 3: Total numbers of physical science students on HE courses at HEIs in the UK at Undergraduate, Masters and PhD levels 2005/06 to 2009/10 (Higher Education Statistics Agency, 2011)

Michael Teitelbaum (2007) argues that a cyclical STEM crisis, dating back to the Second World War, exists in America that he calls “alarm, boom and bust.” This cycle starts when “someone or some group sounds the alarm that there is a critical crisis of insufficient numbers of scientists, engineers, and mathematicians” (Charette, 2013, p. 48) and as a result the country “is in jeopardy of either a national security risk or of falling behind economically” (Charette, 2013, p. 49). An ensuing ‘boom’ phase then occurs, where governments respond with incentives. This response of incentivising STEM continues until supply exceeds demand and a ‘bust’ ensues, whereby graduates then cannot find relevant jobs. This oversupply of STEM workers may have a beneficial effect on economies (National Academy of Sciences, 2006)[17], whereby the graduates may find productive employment in other sectors, however there is also the danger that students avoid the over-supplied subjects and thus create a shortage resulting in the next 'alarm' phase.

There is some evidence that there are increasing numbers of students taking up STEM subjects; the data from

Figure 4 indicates that A 'level (AS and A2) STEM numbers have been steadily increasing from 2010. Although numbers choosing biology have almost stabilised, chemistry and mathematics have been increasing steadily. This may be significant in terms of Teitelbaum's 'bust' scenario, where students who wish to continue down the STEM pathway are selecting subjects (i.e. chemistry) that hold more potential for future employment than those with less guarantee (i.e. biology) (Select Committee on Science and Technology 10th report, 2011).

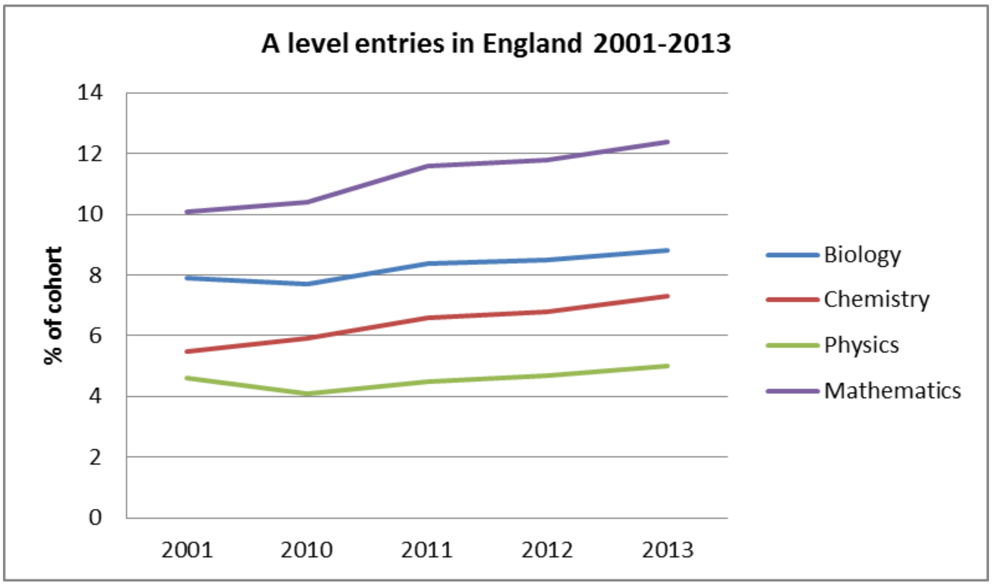

Figure 4: Total AS and A2 level entries in England 2001-2013 (Graph generated using data from Truss & DfE, 2013)

During the period up to 2010, concerns over STEM teacher shortages reached new heights (Ingersoll & Perda, 2009), and high-profile reports from both the National

[17] An analysis by Weinstein has also stated, "A growing influx of foreign Ph.D.'s into U.S. labour markets will hold down the level of PhD salaries" and highlighting that postdoctoral students are cheaper than fixed contract staff. (Weinstein, 1998, p. 14) This has been reiterated recently in an article in Nature (Powell, 2015)

Academy of Sciences (2006) and the National Research Council (2002) sought to link shortages of STEM teachers to the future growth of the American economy. The Sainsbury Report (2007) also highlighted a 20-year decline in the number of pupils taking A' level physics in the UK. This report led to an increase in initiatives in the UK, aimed at engaging young people into STEM during their compulsory school education (i.e. STEM Cohesion Programme, DfE, 2011; Stimulating Physics Network[18] 2010; Women in Science and Engineering[19] WISE, 2007). These initiatives, guidelines and policies could be interpreted as a response to the predicted catastrophic decline in numbers, as described in Teitelbaum's alarm stage. These will be discussed further in Section 2.4.

Recent figures show that all STEM subjects have seen a significant growth in A' levels compared to other subjects. A report by the HEFCE (2014b) says that "while total numbers of A-level entries remained flat between 2011-12 and 2012-13, the numbers of entries to STEM subjects increased by 6000" (p. 41). Similarly, the same report highlights that whilst numbers of full time undergraduates was falling between 2010 and 2013, in 2012-13, there was a 9% increase in physics undergraduate entrants from 2010-11 (2014b). However, even with this increase in physical science students, the demand from employers remains (CBI/Pearson, 2013).

I am hoping that in my study of educational experiences on a physics degree, I will be able to identify if there are events influencing the swing of my sample population towards or away from occupations in the physics-related sector. Within my analyses, I will examine physics degree courses in order to understand the experiences recollected by the respondents in the context of two different institutions. I will explore the respondents' reflections on how they consider their school education as influencing decisions to continue studying physics to tertiary level. In this way, I hope to gain a little more insight into the significance of my own profession at GCSE level. I also intend to explore whether the respondents' occupational expectations have been influenced by their educational experiences. Thus, I am hoping to be able to

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[18] The Institute of Physics and Science Learning Centres formed the *Stimulating Physics Network* partnership to offer support for teachers and pupils of physics in England. The objectives were 'to improve the quality of pupils' experience of physics and to reinvigorate a culture of physics' (Institute of Physics; Science Learning Centres, 2010)
[19] The WISE (Women into Science and Engineering) initiative, led by the UK Resource Centre, was developed to raise the numbers of women participating in STEM. This collaboration of industry with education was in order to promote STEM careers to girls, highlighting the necessary skills for relevant occupations (WISE, 2007).

contribute a little more towards understanding why there is this conflict between the demands of industry, the occupational choices of graduate physicists and the role that education plays in this.

In the next chapter, I will examine the literature surrounding choices made during the educational journey in relation to occupational goals. In order to do this, I will explore the formation of a science identity and the influences of various factors, including education.

CHAPTER 2 SCIENCE LEARNING, IDENTITY AND OCCUPATIONAL CHOICE

2.1 THE CONCEPT OF IDENTITY

My research explores how educational events may influence occupational decisions that physics students make in relation to the subject they have chosen to study. Decisions to continue into a physics-related occupation may be influenced by a wide variety of factors, but my focus is on education, and specifically university education. In this section, I will examine the literature surrounding the development of a science identity and the significance of this to my study. I will then examine the research on factors influencing science career aspirations, including what part education plays in this.

Carlone and Johnson summarise the value of using identity as a lens for analysis. They cite using identity to develop an equitable science education (as with Eisenhart & Finkel, 1998), and also for examining learning and education as factors in the development of a science identity (Carlone, Haun-Frank, & Webb, 2011). Many others have used the idea of identity to explore how an early interest in science can be sustained through education (e.g., Johnson *et al*, 2011; Aschbacher *et al*, 2010; Brickhouse *et al*, 2000). My exploration is on the educational events that influence individuals during a physics degree courses (i.e. during a process of learning), so I see the development of a science identity as a useful concept in which to view this field. I will interview ten physics undergraduates and graduates to explore their reflections on education, and what events they consider to have influenced their experience and subsequent identification of physics.

Identity however, is not an easily defined theoretical concept: In traditional psychology, identity is considered a trait, or core personality quality (Hewitt, 1997). Characteristically, psychologists view it as an internal phenomenon with external, social or environmental influences (Goffman, 1963; Stryker & Burke, 2000): an identity is informed as one “address[es] and respond[s] to others while enacting cultural activities under conditions of political-economic and cultural-historical conjuncture” (Holland & Lave, 2009, p. 3). Thus, the psychological perspective is inherently complex, relying on this internal ‘self’, together with social context and others’ expectations (Wortham, 2004). I intend to use the term identity from a social practice theory perspective, where “identity reflects one’s ongoing existence in the world” (Barton *et al*, 2013, p. 41) rather than the psychological interpretation.

As identity is constantly remade and socially negotiated, some argue that it is an impossible phenomenon to isolate (Tan *et al*, 2013). Wenger (1998, p. 151) also describes the construction of identity through a layering process where an “interweaving of participative experience and reificative projections” are used to negotiate meaning around us. In the next section, I will examine the literature on how developing a science identity informs my decision to use it as a lens for this analysis.

2.2 The development of a science identity – learning to be a scientist

The concept of identity is frequently used for understanding learning in science; in developing both knowledge and practices, and self-recognition (e.g. Brickhouse *et al*, 2000; Brickhouse & Potter, 2001; Tan & Calabrese Barton, 2006; Carlone *et al*, 2011). Johnson *et al* examined science identities and “ways in which those processes were stable and/or changed over time” (2011, p. 342). Science identity is “the sense of who students are, what they believe they are capable of and what they want to do and become in relation to science” (Aschbacher, Li, & Roth, 2010, p. 566)

Carlone and Johnson highlight the three dimensions of science identity as competence, social performance, and recognition (Carlone *et al*, 2011). This touches on the social theory of learning (i.e., Brickhouse & Potter, 2001), which uses identity to understand how learning influences students to view experiences as worthy or unworthy of engagement. This view opens up the possibilities that an emerging identity in science might involve transitions of who an individual considers their ‘self’ to be, and who they might want their ‘self’ to become (Cobb, 2004).

Lave and Wenger’s (1991) framework of situated cognition emphasises this link between learning and identity formation, although not specifically to science. Within their framework, lived experiences and social interactions influence identity, based on how students view themselves and believe others view them as they participate in various activities. Giddens (1991) also considers identity to be a dynamic process: “self-identity is not a set of traits or observable characteristics, but a person's own reflexive understanding of their biography” (p. 53). My interview data will allow me to examine a sample of physics students' recollections of their educational experiences, and the views that they have of themselves in relation to their subject. Their retelling of educational experiences will map their individual journeys through education, and allow me to explore how their identification with science changes.

Jackson and Seilar (2013) liken identification with science to "motion, rather than a certain location or distance from science at a point in time" (p. 829), thus "one acquires and uses experiences that influence future instances of identity construction" (p. 831). Wenger (1998), who argues that it is a movement through "communities of practice,[20]" continues this concept of science identity as a form of motion. Hence, identity has no fixed course when viewed as a motion over time, instead influenced by many different factors. Wenger calls these factors the "field of influences" which act on an individual's trajectory; thus the trajectory has "coherence through time that connects the past, the present, and the future" (1998, p. 154). This idea of a science identity as a trajectory of science-related constructions represents the "psychosocial formations that develop over a person's lifetime" (Holland *et al*, 1998, p. 5). Barton *et al* (2012) elaborate Wenger's work, describing how "as individuals move through the world—through time and space …they are exposed to, positioned by, and react to a range of people as well as institutional and cultural structures and forces" (p. 41).

An educational journey can thus be seen as a passage through time, "transforming the 'identity-in-practice,' into 'an increasing sense of identity as a master practitioner'" (Lave & Wenger, 1991, p. 101). This frames my view for the foundation years of a university degree: the time where individuals continue to develop their science identity, learning the skills on their journey towards becoming an expert. However, during this educational journey, their identity encounters different events and interactions, the fields of influence, within the community of practice. These events may lead students to question their science identity, which in turn may affect their persistence towards a future in science. It is these that I am interested in

[20] Communities of practice (CoP) are summarised as "groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly." The learning that takes place is not necessarily intentional. Three components are required to be a CoP: the domain, the community and the practice. (Wenger, McDermott, & Snyder, 2002, p. 4)

exploring: the fields of influence during the physics degree that shifts the student towards or away from a future in the subject.

2.3 Education, occupation and becoming a scientist

As I explore these experiences during a physics degree, I hope to find out whether these influence occupational decisions by physics students. Thus, I have examined the literature on possible other influences for occupational choices. A search returned much discourse on career development theory; from the psychological origins by Super (1957), to more recent compromises of individual preference, expectation and experience (Ginzberg, 1972). Roberts questions the usefulness of developmental theories, describing choice as an irrelevant and naïve concept (2009). Instead, he argues that occupational opportunity forms from the 'push' from family background, gender, prior attainment and similar 'ascribed statuses,' and the pull from employers and the labour market: "Together they create distinct career routes, which govern young people's progress" (Roberts, 2009, p. 355). Using both these perspective, I take occupational choice to be influenced by both developmental theory, with aspiration and life experience serving to shape decisions, together with those external factors described by Roberts as a 'push,' although I prefer to think of those being less of a push than a focusing in a certain direction.

Smyth and Banks (2011) describe how decisions to go onto higher education are shaped by three processes: life experience, institutional habitus[21] and conscious assessment of different options. Further studies have examined how student self-efficacy (Glynn, Taasoobshirazi, & Brickman, 2007); ethnicity and socio-economic status (O'Brien, Martinez-Pons, & Kopala, 1999) and gender differences (Britner, 2008) shape occupational decisions. Wang & Staver (2001) argue the early ideas, of what might or might not become an occupation are honed during the course of education. In terms of science occupations, research by Hill *et al* (2011) highlights the middle school years as crucial, where science interest and participation may drop even with high attainment. Lindahl's (2007) longitudinal study of Swedish girls also found that

[21] Institutional habitus can be regarded as the impact of a social group on an individual's behaviour as it is mediated through organisations such as schools (McDonough 1997; Reay, David, and Ball 2001, 2005).

career aspirations form early in adolescence and beyond this, engagement in science became more difficult.

Based on my experiences in education and anecdotal evidence from interviewing science students, the idea of ‘becoming a scientist’ starts as an early aspiration (Head, 1997), encouraged by family (Gilmartin, Li, & Aschbacher, 2006), (Ferry, Fouad, & Smith, 2000) and societal influences (Stake & Nikens, 2005). Subsequently, it is shaped by surrounding systems with maturity and experience (Seymour & Hewitt, 1997). Studies have found that school science contributes significantly to aspirations of continuing science and so can be considered an important factor in the fields of influences (Chouinard, Karsenti, & Roy, 2007; Stake & Mares, 2001).

A literature search into the concept of choice at higher education returned many studies on the different factors influencing individuals to enter tertiary education. These include educational inequality (Smyth, 1999); geographical distance (Spiess & Wrohlich, 2010); socio-economic class (Reay, David, & Ball, 2005); ethnicity (Long, 2004) and careers guidance (McCoy *et al*, 2006). Other studies combine individual and social factors: prior attainment, social and cultural factors (Ball, Davis, & Reay, 2002) and patterns of social advantage and disadvantage across generations (i.e. Bloomer & Hodkinson, 2000). Ball *et al* assert that: “the perceptions and choices of prospective higher education students are constructed within a complex interplay of social factors” (p. 53) They also conclude that higher education is not “the same experience for all, neither is it likely to offer the same rewards for all” (2002, p. 872). Well-documented barriers to participating in higher education are also described by Archer (2003) and Gorrad *et al*, (2007), with Byrom’s (2009) study highlighting how increased numbers of higher education entrants has not resulted in a more diverse student body.

As I am examining stages of education where the individuals have completed the initial stages of their educational trajectory; chosen and invested in a future that involves participation in physics, the complexities of higher education choice and experience based on social class, gender and ethnicity is beyond the remit of this study, although I acknowledge that these are significant influences. For the purposes of this study, I will focus solely on the educational experience as the field of influence affecting occupational choice. In the next section, I will look at the patterns in science uptake in recent years, and examine how policy makers are investing in science education to increase participation.

2.4 Science education: trends and changes

Policy makers in the UK have introduced substantial investment in STEM education and initiatives over the last few years (WISE, 2007; Institute of Physics; Science Learning Centres, 2010), in order to encourage more uptake in STEM subjects. Each one is part of the program to tackle the crises in STEM skilled labour, following the STEM Programme Report (2006) published by the DfES and DTI which called for better coordination of organisations involved in STEM education. The STEM Cohesion Programme was formed to bring together many stakeholders to support the promotion of STEM subjects.

Each initiative aims at various points in compulsory education, designed to increase the numbers of individuals into sciences. Many focus on secondary school education, as "a considerable body of evidence now exists that, compared to other school subjects; science is failing to engage young people" (Archer *et al*, 2010, p. 1). As a result, many organisations now work to engage young people with STEM, running competitions and investing heavily to encourage young people into STEM A 'level. This not only includes opportunities for an enriched educational experience for students, but also teacher professional development and curriculum resources (Rietdijk, Grace, & Garrett, 2011).

In order to understand the progression of a person from secondary to tertiary level education, it is necessary to examine the qualifications that people acquire through this journey. Initially, science and mathematics are considered core (compulsory) subjects in the English National Curriculum (Department for Education, 2014). These subjects are taught throughout the primary and secondary stages of education. There is an option for students to take triple (separate) sciences instead of double science at GCSE; this is the recommended route to taking A' level sciences. Analysis by Hampden-Thompson *et al* (2011) indicated that out of the 567,000 students who were entered for full GCSEs in 2007, 439,000 took double science (77.1%), while only 75,000 (13%) took physics and chemistry GCSE. More recent data from Ofqual (2014) shows that the total number of Year 11s[22] taking GCSEs decreased in the summer 2013 from 5,293,000 to 5,085,000 in 2014, a decline of 4 %, although entries for core and additional science grew relative to this decline. Whilst double science increased by 18% to 297 000, biology decreased 12% (128 000); chemistry decreased 11% (130 000) and physics decreased 9% (132 000).

As indicated above, physics is a considered a numerically smaller discipline than either biology or chemistry and so it is frequently cited as having the most severe shortages, (e.g., National Academy of Sciences, 2006). I have used data from the Joint Council for Qualifications GCSE results data (2013) to illustrate the trends, seen in Figure 5. The data shows although physics is numerically smaller, it has one of the highest percentage of A* grades, along with mathematics and further mathematics; in terms of the sciences, it has a higher percentage of A* compared to biology and chemistry.

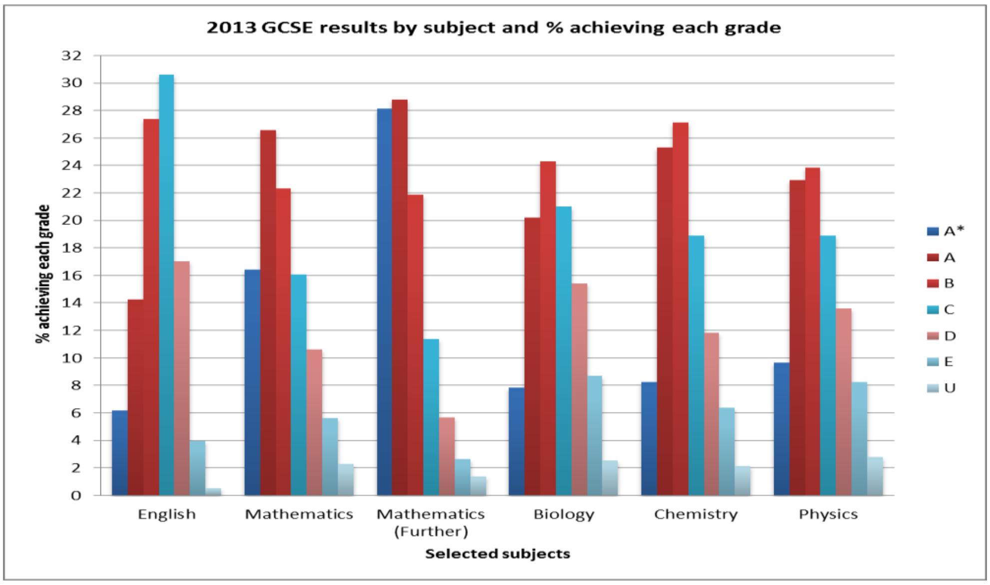

Figure 5: 2013 GCSE results by subject and percentage achieving each grade (Graph generated using data from the Joint Council for Qualifications (2013)

[22] School performance measures changed in September 2013 meaning that only the first result in a subject would count towards performance tables. This led to a decrease in early entry (Year 10) entries (Gove, Changes to early entry at GCSE, 2013)

The Select Committee on Science and Technology (2011) has reported that chemistry, biology, maths and physics appeared to be more difficult A' level subjects[23], as have Coe *et al* (2008) who also conclude that chemistry, physics and biology A' levels are harder than other subjects. There may be some suggestion here that those who enter into separate science and further mathematics are the more able and consequently the percentage of those obtaining A* are far greater than the grades of subjects which are considered less difficult; however it is also worth noting from Figure 5 that physics has the highest percentage of U grades.

In my research on A' levels, I also examined the cohorts taking GCSE in preceding years. The data in Figure 6 below illustrates the ratios of GCSE results in STEM subjects for the 2009 and 2010 cohorts. It is evident that although almost half of students achieved grades A* to C in at least two sciences (and mathematics), far fewer achieved the same in all three sciences and mathematics. This indicates almost half the cohort is no longer considered potential for STEM A' levels, and thus considered 'leakage'[24] from the STEM pipeline.

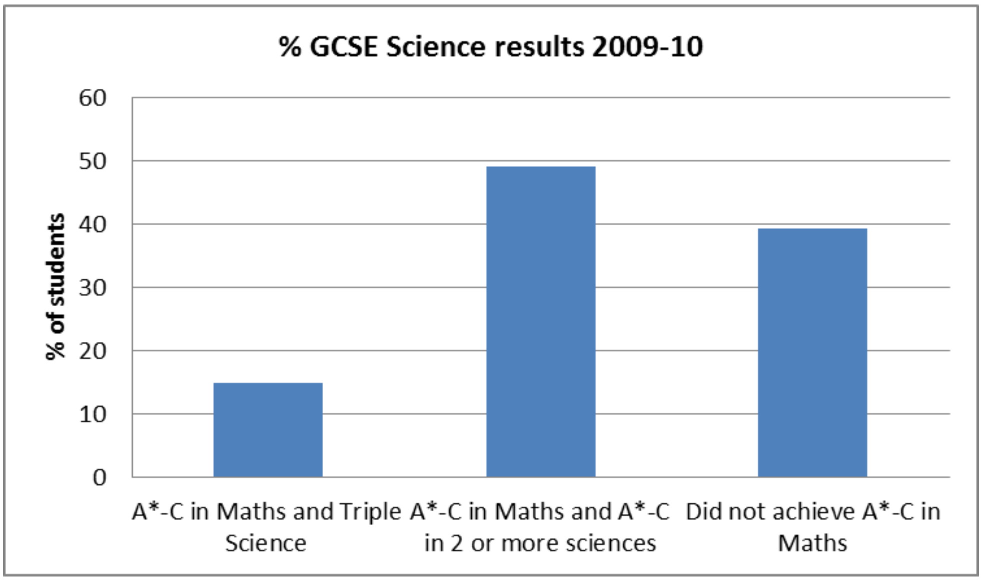

Figure 6: Cohort of GCSE results in 2009/10 (Graph generated using data from Morgan, 2012)

[23] They compared average A' level points obtained with comparable GCSEs, and showed that students taking these subjects could expect a significantly lower grade than those taking other subjects at A-level.
[24] See footnote 10 on page 21.

Looking at A‘ level STEM combinations, mathematics seems to be the most popular, whereas mathematics and physics is least popular (see Figure 7), with fewer people taking this option than those choosing three STEM subjects; in the main these were biology, chemistry and mathematics (Truss & DfE, 2013). This data, collected during the period of economic recession, suggests that subjects with the greatest perceived potential for employment and earnings are being chosen by students (The Complete University Guide, 2012).

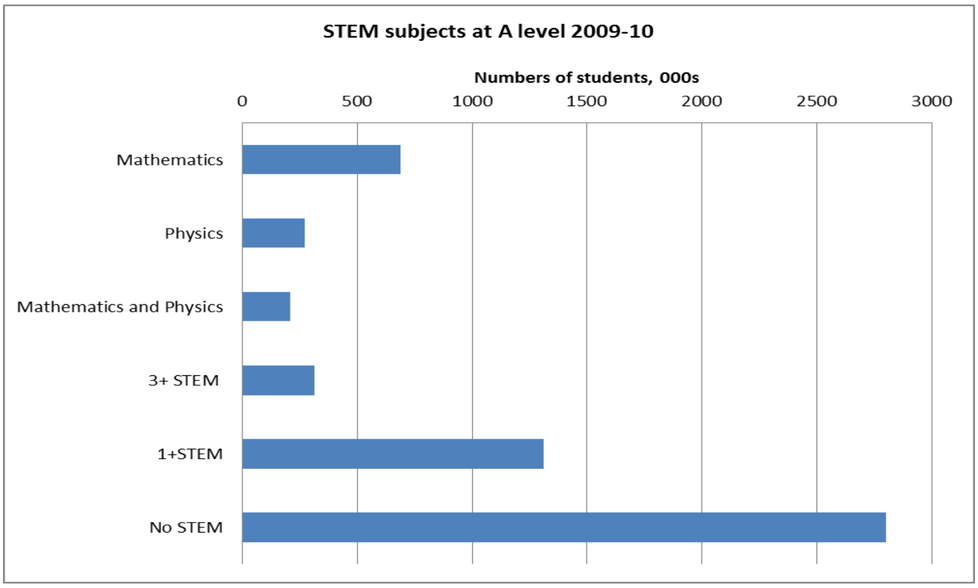

Figure 7: STEM A ‘level (AS and A2) options 2009-10 (Graph generated using data from Truss & DfE, 2013)

A more detailed examination of GCSE and AS level grades illustrates a far greater proportion of students with an A* in chemistry take it up than either biology or physics. In fact, as is illustrated in Figure 8, 59% of A* grade students took chemistry AS level compared to 51% for biology and 43% for physics. At the lower end of the grades, AS biology has the highest proportion of A*- C pupils, 36% compared to 34% for chemistry and 25% for physics. Physics sees the lowest percentage (4%) of pupils taking up the AS level from a C grade in GCSE.

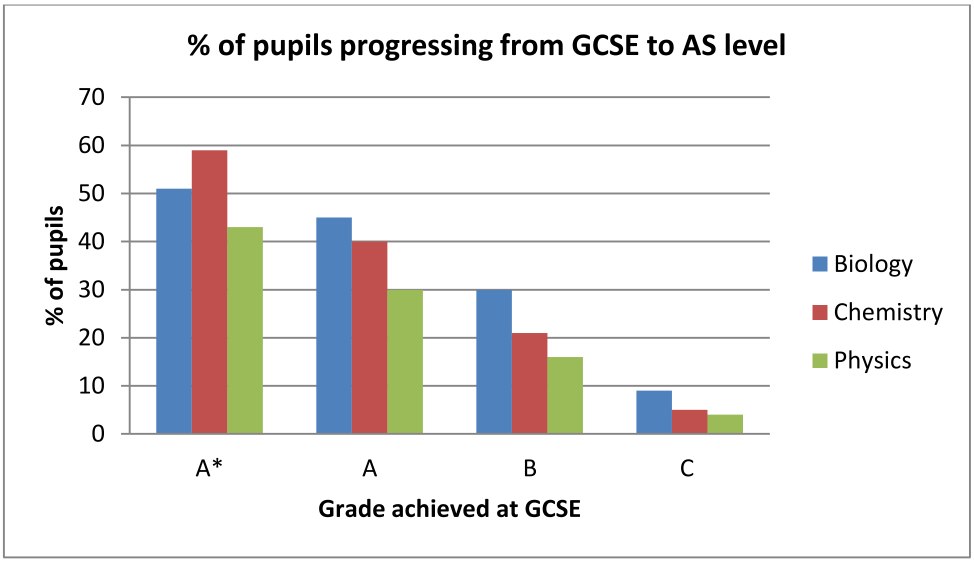

Figure 8: Progression rates from GCSE to AS level by science subject and grade (Graph generated using data from Department for Education, 2012b)

Figure 9 illustrates data from CaSE and BIS showing that GCSE A* students also often opt to study chemistry A2 than biology. This may be because biology-related jobs are particularly competitive (AGCAS and Graduate Prospects Ltd., 2012). Destination data also suggests that more than 50% of chemistry graduates work in jobs directly related to their degree, whereas only a small minority of physics graduates use physics expertise as a major part of their work (AGCAS and Graduate Prospects Ltd., 2012).

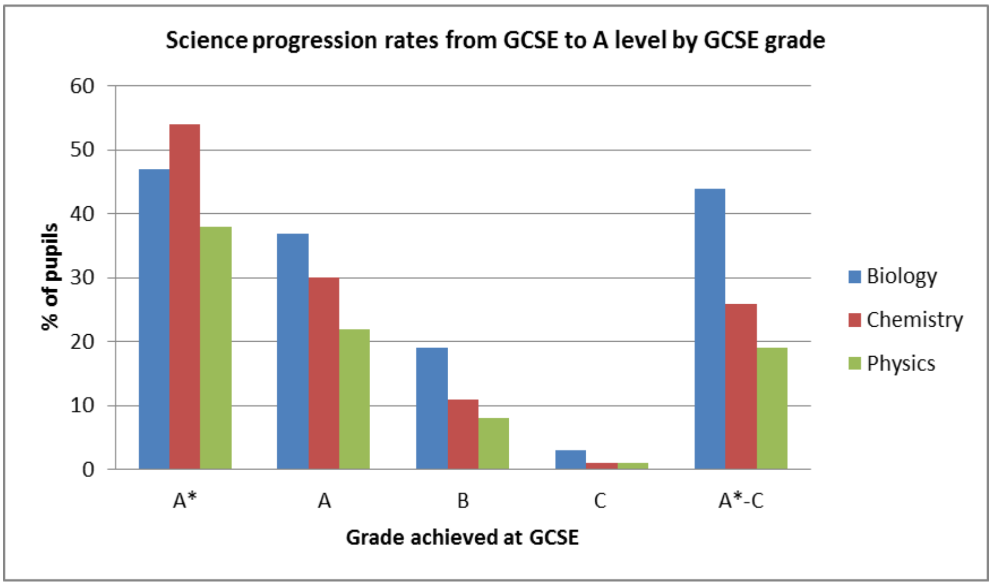

Figure 9: Science progression rates from GCSE to A2 by GCSE grade (Graph generated using data from DfE, Education Standards Analysis and Research Division, 2012)

Examining both AS and A2 entries for individual sciences shows that numbers of girls taking physics have declined (along with boys taking biology). The following three graphs illustrate the changing numbers for science entries at A' level:

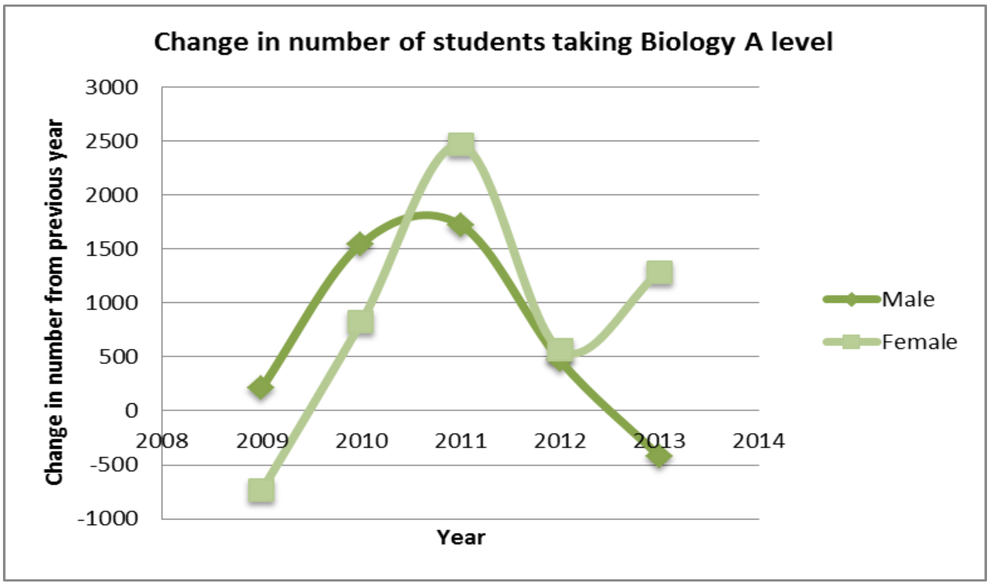

Figure 10: Change in number of students taking Biology AS and A2 (Smith B., 2013)

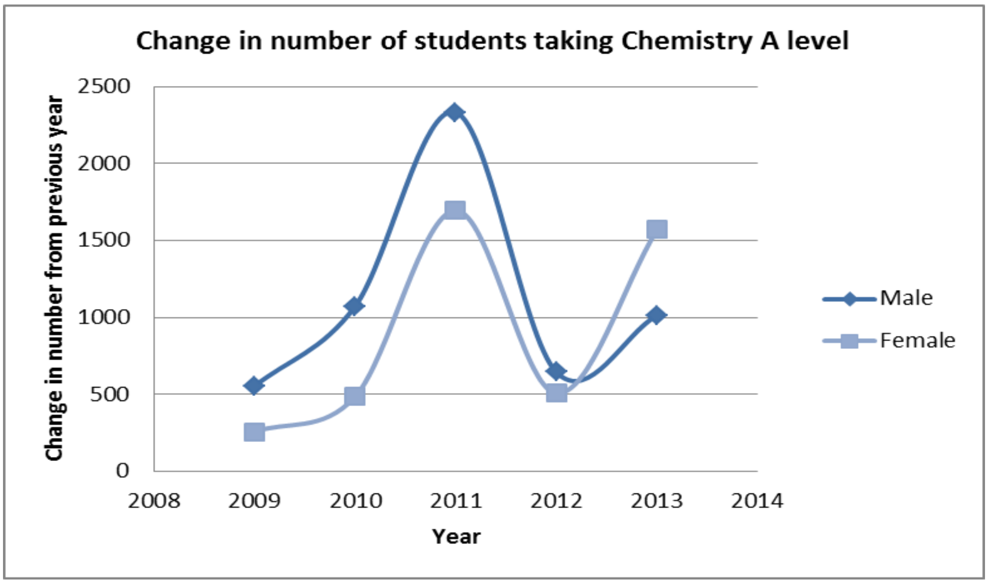

Figure 11: Change in number of students taking Chemistry AS and A2 (Smith B., 2013)

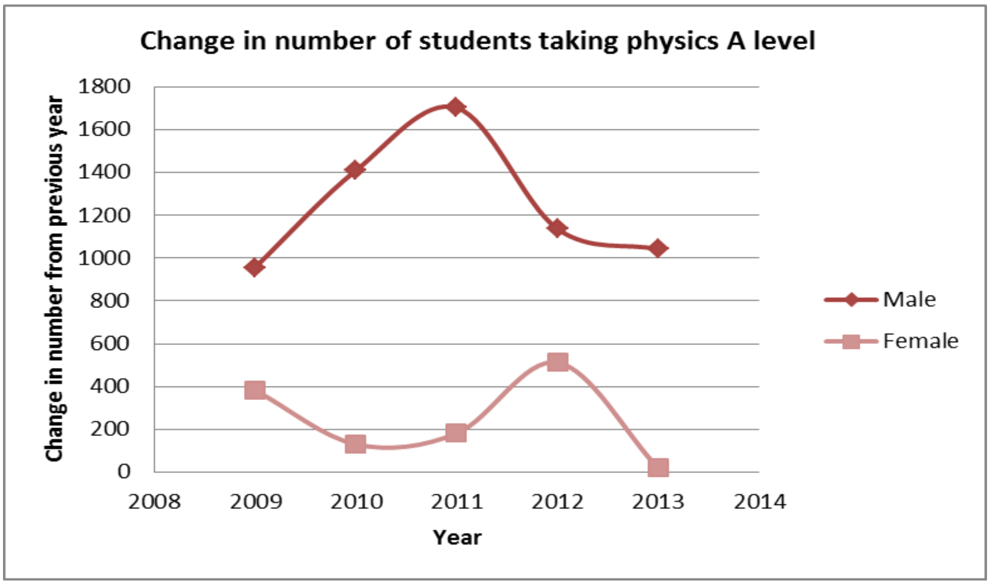

Figure 12: Change in number of students taking Physics AS and A2 (Smith, 2013)

This data illustrates growth; between 2012 and 2013, chemistry entries increased for both boys (+1014) and girls (+1570), and although the male uptake of biology has declined by 422, and in physics A' level for females (entries were only up by 18), there were 1042 more male physics entries. This suggests that A 'level chemistry is considered to be a subject much in demand by both males and females, unlike the other two sciences.

2.5 Perceptions of STEM careers

A report by the Wellcome Trust in 2013 found that people perceive studying science as being helpful for career prospects (Clemence, et al., 2013). Seventy percent of adults thought that good science understanding could improve occupational prospects, while a similar proportion of young people (69 %) thought that science lessons provided useful skills for most jobs. In the report, 82% of the 380 young people surveyed gave positive reasons for science in terms of employment, as shown in Figure 13:

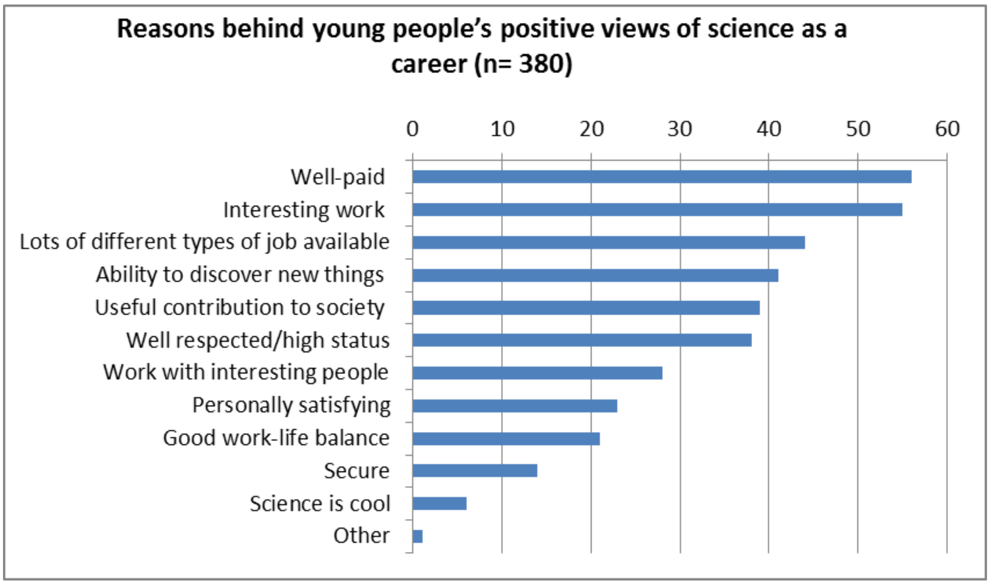

Figure 13: Reasons behind young people's positive views of science as a career (Clemence *et al*., 2013)

The 2006 PISA survey[25] conducted by the OECD (Bradshaw *et al*, 2007) also found that 84% of UK students[26] reported that learning science was important. Seventy-one per cent also agreed that studying science would improve occupational prospects; however only 34% said that they would want a science-related career and fewer still (13%)[27] said they would work in a career using science expertise. The NFER (2011) also surveyed 238 school pupils to examine the changes introduced by STEM enhancement projects and found that pupils had positive perceptions of STEM careers, with a majority of pupils (69%) feeling that STEM careers were useful and interesting. As it was a small sample however, it is not as nationally representative as the PISA survey.

The Wellcome Trust report (Clemence, et al., 2013) also suggests links between perceptions of science at school and science as a career: 47% of students who found school science lessons interesting were also interested in a future science career; however, this also had a small sample size of 380, so again difficult to say whether it is statistically significant. Even among these 380 young people interested in school

[25] The Programme for International Student Assessment (PISA) is a survey of the educational achievement of 15-year-olds organised by the Organisation for Economic Cooperation and Development (OECD) and carried out the National Foundation for Educational Research (NFER). In England 169 schools and 4935 students participated in PISA 2006. This represents 89% of sampled schools and 89% of sampled students and can be considered nationally representative.
[26] Compared to an OECD average of 73%.
[27] Compared to the OECD average of 21%

science, 53 % had no interest in pursuing a science career. This reflects the distinction that Archer *et al* (2010) found between attitudes to 'doing' science and 'being' a scientist. Both the PISA data and a study by the Department for Education (2011c) reiterate this point: the perception that a good science education can lead to better employment and contribute to better skills, but a future career in science not desired. As shown in figure 14, very few young people (13%) viewed science careers through a negative lens, giving number of qualifications and competitiveness of the job market as important reason for their views.

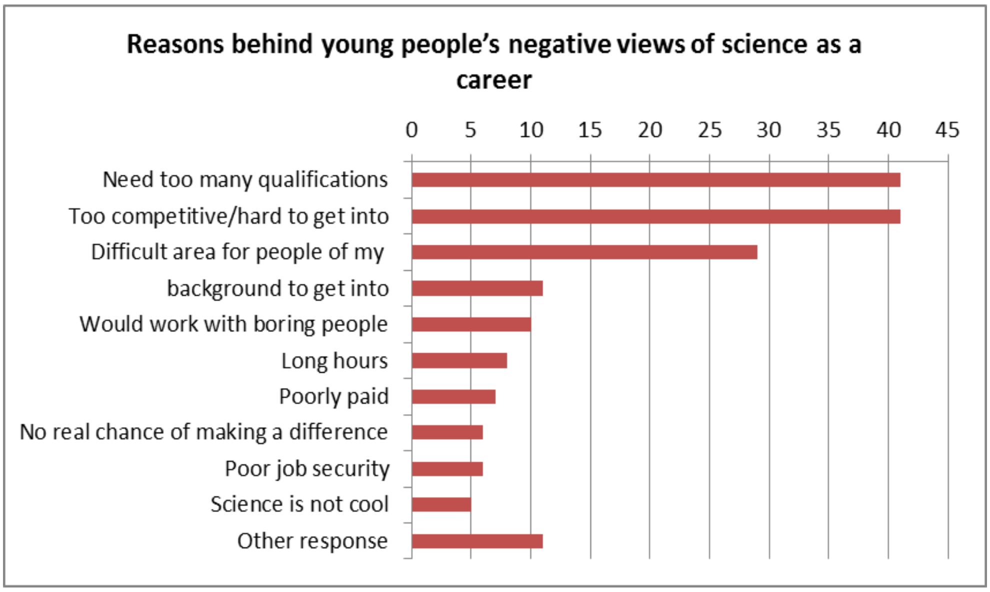

Figure 14: Reasons behind young people's negative views of science as a career (n=60) (Clemence *et al*., 2013)

It seems a contradiction exists here, with young people, albeit a small number viewing the competitiveness of the job market as one of the reasons for not pursuing science, and yet there is the remains the much-publicised demands from industry[28].

2.6 Influences in attitudes to STEM occupations

The Wellcome data found that parental influence was an important influence for a young person's aspirations to a scientific occupation. Amongst those with one

[28] as previously described on page 18

parent interested in science, 47% were interested in a future science occupation, compared to 35% with both parents uninterested in science. This importance of parental attitudes in young people's occupational aspirations has been found both qualitatively and quantitatively as part of the ASPIRES study (see Archer *et al*, 2012; 2013). Furthermore, Archer et al found that the more exposure people had to science, the more useful it was considered to be for future occupations. It is worth noting that Clemence *et al* (2013) found that in 2012, adults became less positive about science and occupational prospects than in 2009. They suggested this reflected concerns over job prospects from the preceding economic recession.

From the data presented here, I can see that there are various issues emerging: early exposure to science or scientists is considered influential to young people and job prospects are perceived to be better for qualified scientists. The increasing numbers studying science all seem to indicate that the initiatives are working. However, it must be remembered that the economic crisis is a relatively recent occurrence and remains in the social memory. This, together with societal concerns about employment, may have also influenced some students to take STEM subjects with their perceived economic importance (Clemence, et al., 2013).

2.7 The destinations of science graduates

Research has shown a diverse picture of graduate transition from higher education into work, especially in employability and occupational pathways (Candy & Crebert, 1991; Graham & McKenzie, 1995). There is a growing interest in enhancing student employability, possibly a consequence of "the development of a knowledge-based economy in an increasingly competitive global market" (Harvey, Locke, & Morey, 2002, p. 4). This requires a well-educated workforce competing in the global market, and hence pressure on higher education to supply labour markets with a skilled work force adaptable to different situations (Candy & Crebert, 1991). This section elaborates on the research dealing with these issues.

Figure 15 (overleaf) shows the percentage of graduates in different areas in 2012-13, and it is evident that a much higher percentage of graduates are in either full-time work or full-time further study.

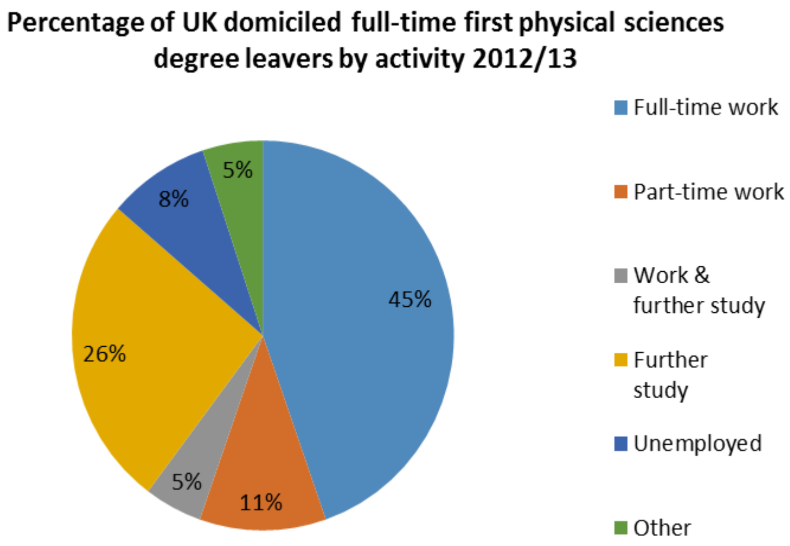

Figure 15: Percentage of UK domiciled full-time first physical sciences degree leavers by activity 2012/13 (Graph generated using data from the Higher Education Statistics Agency, 2014)

Employers[29] indicate that difficulties remain in recruiting graduates, and continue to demand for STEM graduates. The Department for Innovation, Universities and Skills (DIUS – now BIS) (2008) has highlighted future shortages of skilled workers, and Engineering UK identifies similar shortages in manufacturing (Royal Academy of Engineering, 2012). Smith (2010) analysed the shortfall of scientists using data from HESA and UCAS, and concludes that although the numbers taking physics at A' level and degree level have increased; the initiatives to increase the numbers of graduates had little impact on the shortfall.

A study[30] by Macmillan and Vignoles (2013) found that, six months after graduation, around 50% of new science graduates were in high status occupations, i.e. higher and lower professional, management and administration. Three years after graduation, they noted that more than one in ten had entered the field of education, whilst just 1.5% had entered the field of science. This study also noted that those in the sciences, maths and computing, social studies, law, linguistics, languages and

[29] In 2013, the Manpower Group's Global Talent Shortage Survey (2013) for that mechanical, electrical and civil engineers were in a short supply globally. The CBI/Pearson Education and Skills survey (2013) also showed that demand for STEM skills at graduate level and below remained high.

[30] Using data from the Higher Education Statistics Agency Longitudinal Destination of Leavers from Higher Education on first degree graduates leaving higher education in 2006/7

history were most likely to undertake postgraduate study, with the highest proportion (one in five) entering postgraduate study in the physical sciences.

The high percentage of STEM graduates working in fields not directly related to their field of study makes the case more difficult to increase graduate numbers without more understanding about the market forces involved. It is an unanswered question as to why the apparent shortage of scientists co-exists with a large proportion of graduates working in unrelated occupations (Department for Innovation, Universities and Skills, 2009). Deloitte (2012) calls this problem 'the talent paradox': "While there is a surplus of job seekers, some companies are facing shortages in critical areas where they most need to attract and keep highly skilled talent" (p. 7).

Data from the BIS (2009), and the Higher Education and Statistics Agency (2012) showed that many physics graduate were going into non-scientific occupations. The Review of UK Physics survey (Institute of Physics, 2012) pointed out that the many physicists choosing to work in non-scientific occupations would damage the discipline. This indicates, however, that it may be this flexibility that makes physics more attractive to study (Wakeham, 2008). The HESA data in Figure 16 indicates that the majority of recently graduated physicists are employed in professional and technical occupations, but similarly a large number are working in non-related employment.

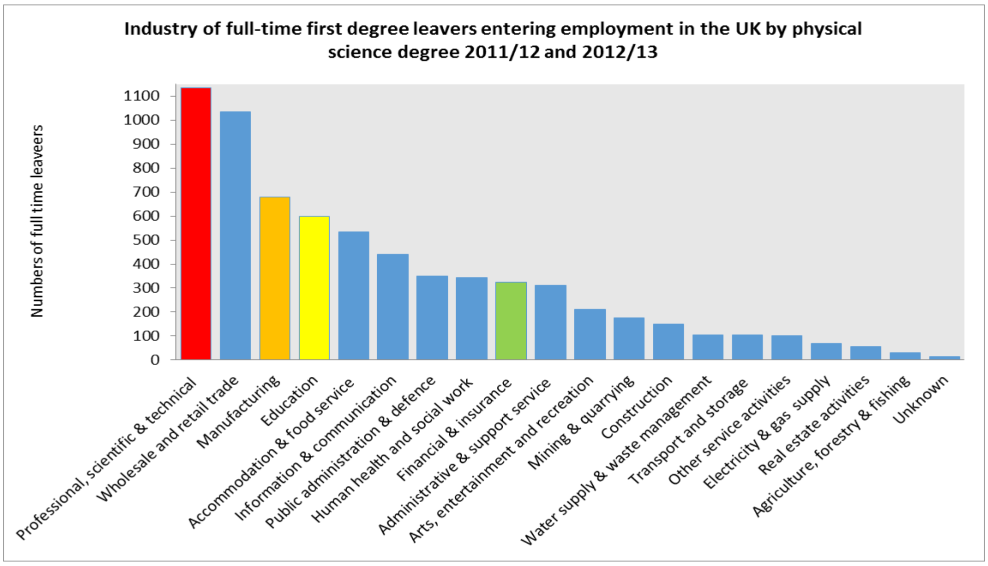

Figure 16: Industry of full-time first-degree leavers entering employment in the UK by physical science degree 2011/12 and 2012/13 (Graph generated using data from HESA, 2014)

It may be that initial occupation is a misleading statistic as many graduates experience significant events following graduation, such as moving back home. Elias (1999) found that a significant proportion of new graduates experienced a short spell of unemployment after graduation, but these were mostly transitory. He found that:

> Despite its predominantly transitory nature, it took about two years after graduation for unemployment among 1995 higher education leavers to stabilise at its minimum level of about 2 to 3 per cent (1999, p. 7).

It is more reliable to examine occupational data after some period of time. In Figure 17, the generalised STEM data on employment three and a half years after qualifying indicates significant numbers entering occupations not considered scientific (Higher Education Statistics Agency, 2012).

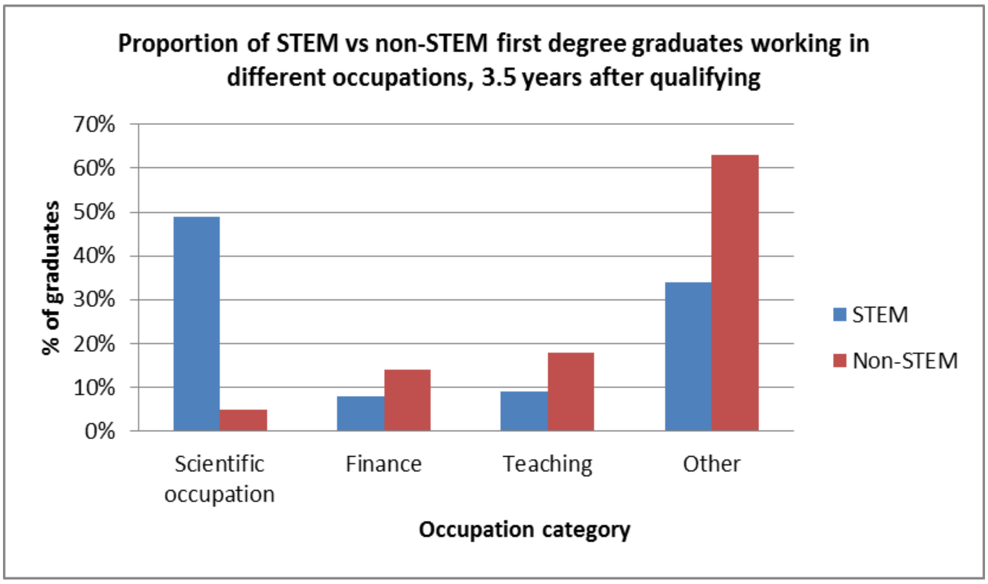

Figure 17 Proportion of STEM vs non-STEM first-degree graduates working in different occupations, 3.5 years after qualifying. (Graph generated using data from the HESA, 2012)

An important factor to also note is changing arena of occupations nowadays, with frequent job changes trending towards normality. Retaining employees has become an increasing challenge over the last few years for employers (Chartered Institute of Personnel and Development, 2013). A longitudinal study by the US Bureau of Labour Statistics (2002) reported that on average young people changed employment[31] 9.6 times between 16 and 36 years, with over two-thirds held before 28 years old. By 2012, this had risen to an average of 11.3 jobs between 18 and 46 years, with nearly half of all jobs held before 25 years (Bureau of Labour Statistics, 2012). The security of a 'job for life' that characterised the workplace a few decades ago has given way to short-term contracts, "'intelligent careers' and 'career portfolios'" (Nabi & Bagley, 1998, p. 31). If people switch employment every two years, having a lifelong career now seems more myth than reality. Twentieth century employment involved long-term jobs, mutual loyalty and security between employer and employee; however, the 21st century seems more based on short-term goals and positive-sum games (Bureau of Labour Statistics, 2012).

Studies indicate that students leave university with initial expectations (in terms of job satisfaction, salary levels and professional development opportunities) about their future work (Graham & McKenzie, 1995; Harvey, 2000). The Institute of Physics longitudinal study of physics students (2010) illustrates that over 50% of physics graduates aimed for employment and many towards further study (figure 18):

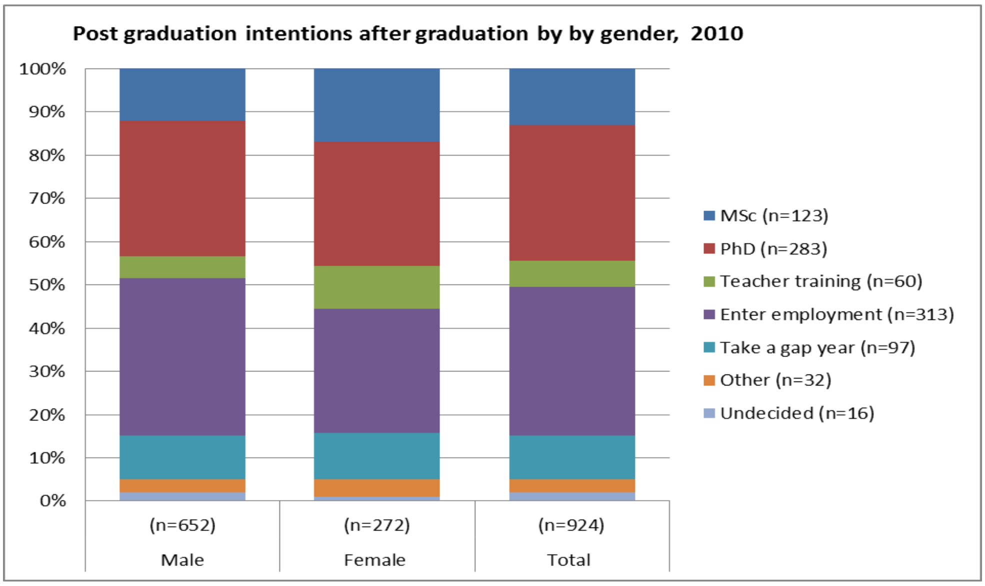

Figure 18: Post graduation intentions after graduation by gender (Institute of Physics, 2010)

In her analysis of university entrants, Smith argues, "the sciences appear to have retained their share of the undergraduate population, providing no evidence for a

[31] In this study, employment was defined as an uninterrupted period of work with a particular employer.

swing from science at this level" (2010, p. 294). It seems that the perceived shortfall of physics graduates comes from employer demands and their unsuccessful attempts to recruit skilled graduates.

2.8 The destinations of physics graduates

This discussion so far has focused on science graduates, whereas I am specifically interested in physicists. The Royal Academy of Engineering (2012) emphasises that physics degrees should not target only future physics academics, but also future employees. Studies reveal that physicists find employment in a wide range of sectors, often far from those conventionally thought of as physics-based (Institute of Physics, 2001). The Review of UK Physics highlight that many physicists are engineers by trade, which in their words "tended to make physicists invisible" (Jagger *et al*, 2001, p. 5). Melville (2007) argues that it is common for "university physics departments to withdraw from applied research and effectively to pass on applied work to the engineers at an early stage" (p. 81), leading to substantial numbers of physicists working in engineering.

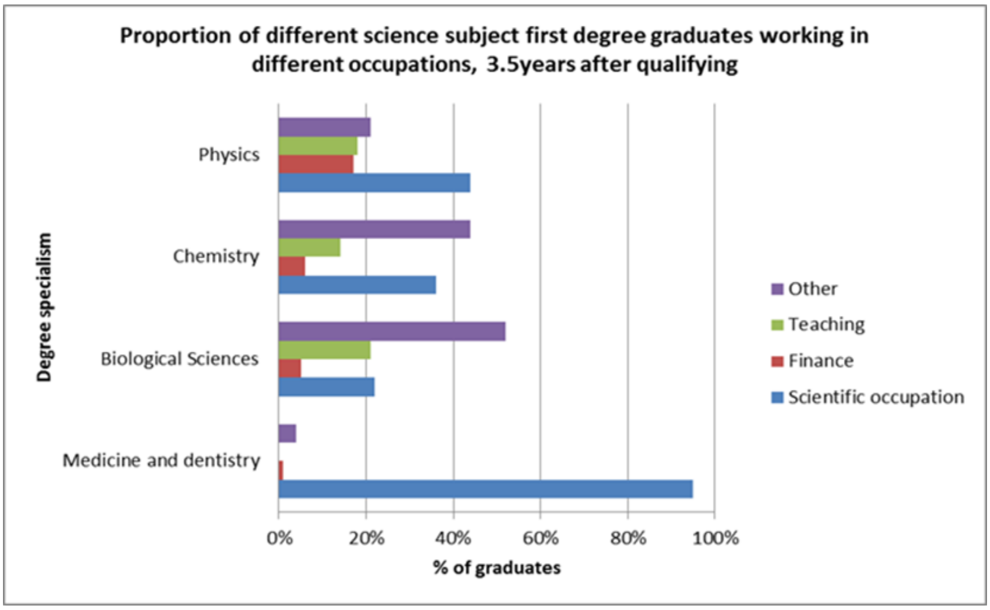

Figure 19: Proportion of different science subject first-degree graduates working in different occupations, 3.5 years after qualifying.

As seen in Figure 19, the most common employment of physicists in non-physics roles is in financial services, as these utilise problem-solving skills integral to physics degrees (Jagger *et al*, 2001). Around 9% of STEM graduates (14-18% of physical sciences graduates) go into teaching, with 8% working in finance. The STEM subject group most dominant in finance is mathematics (20-33%); however, there are still a relatively large number of physicists. Wakeham (2008) found that physics graduates were preferred to those from business studies and economics. As an example, a report on the London-based hedge fund, Winton Capital, stated that it preferentially employed physicists and engineers. It employed more astrophysicists than economists to "make patterns out of the noise" (Costello, 2011, p. 1); within this one company, there were 38 computer scientists, 27 mathematicians, 12 physicists and 14 engineers. Extensive research (Bratti *et al*, 2003; Chevalier, 2011; Walker & Zhu, 2011) has shown that the average return to any degree remains high with graduates earning more than non-graduates do, but as the financial sector pays exceptionally attractive salaries, "there is no real problems filling the vacancies" (Jagger *et al*, 2001, p. 9). Research on these high salaries for science graduates in finance suggests that it is unlikely these are causing the shortage of scientists (Department for Innovation, Universities and Skills, 2009). It does however, cause problems for academia and smaller firms, who argue that the large salaries diminish numbers and quality of graduates available for them.

2.9 STEM SKILLS AND SCIENCE GRADUATES

The Chartered Institute for Personnel and Development (2013) noted that three quarters of UK companies[32] experienced recruiting difficulties, primarily because applicants lacked technical or specialist skills. In their study, they found there was a threefold increase[33] of competition by different organisations for well-qualified talent, reflecting a growing mismatch between the skills demanded for by employers and those available in the labour market. The survey also found over a quarter of organisations believed that schools, colleges and universities were poor at equipping

[32] based on 462 respondent organisations from the UK
[33] from 20% in 2009 to 62% in 2013

young people with the appropriate skills, with respondents suggesting that education focused too much on theory and academic excellence (Chartered Institute of Personnel and Development, 2013, p. 26).

In November 2013, the UK Commission for Employment and Skills also analysed the supply and demand for STEM graduates (Bosworth, Lyonette, & Wilson, 2013). They found that core STEM occupations employed about 45% of graduates with STEM degrees in 2011. However, from the 2011 graduates, only one-third (33%) were employed in a core STEM job, compared with 45% of 2001 graduates. Over two thirds (66%) were working in a non-STEM sector, up from 52% in 2001. This suggests that the increase in more specialised STEM subjects, such as sports science, may not be providing the STEM skill-set wanted by employers. It might also be a consequence of the recession, causing a trend of STEM workers to spread throughout the workforce: the recession driving graduates to take whatever jobs they can find (Chartered Institute of Personnel and Development, 2013).

A survey of physics graduates from 2011 indicated that, six months after graduation, just over a third of new graduates were employed either full or part time (Higher Education Funding Council for England, 2014a). It is therefore questionable as to whether there actually is a shortfall of graduate scientists or whether, as was mentioned by Melville (2007), there is a shortage of appropriate skills required by employers. Charette argues that having an oversupply of STEM workers "gives employers a larger pool from which they can pick the 'best and the brightest,' and it helps keep wages in check" (2013, p. 5), thereby implying that there is a demand for more investment to generate more choice.

It seems that many employers believe that science graduates are inherently employable in professional occupations, whilst berating the fact that there is also a skills deficit. Melville (2007) asserts that "physics graduates have no difficulty in finding employment over a wide range of fields, but consideration should be given to more commercial or applied aspects on the course to give them a wider range of skills." A recent quote from the CBI states that:

> Recruiting staff with strong science, technology, engineering and maths (STEM) skills will help underpin the UK's ability to compete and achieve growth in many major

> sectors like manufacturing, construction and engineering. People with STEM skills are recruited at every level from apprenticeship entry (43%), technicians (40%) and graduates (53%). But 42% of firms struggle to find the STEM talent they require.
>
> (Confederation of British Industry, 2012, p. 40).

This report highlighted the 42% of employers requiring staff with STEM skills reported difficulties in recruitment, while 17% faced difficulties in recruiting graduates (2012). Charette argues that “it may be that the shortage of STEM workers being referred to could be better described as a shortage of ideal candidates” (2013), where employers seek a larger pool of skilled graduates in order to select an elite. An HEFCE-commissioned review (2009) pointed out that employers seemed to becoming more demanding, thus struggling to fill vacancies because few candidates could match their criteria.

An Institute of Physics report also noted that there was a perceived decline in practical skills of physics graduates. They described how undergraduate syllabi often contained too much theory, with practical applications often only the application of models or simulated projects (Institute of Physics, 2001). In my professional experience, and supported by the literature I have read (Donnelly *et al*, 1996; Bhathal, 2011; Sneddon *et al*, 2009; Abrahams & Millar, 2008; Abrahams *et al*, 2014), there is evidence that sometimes the education system teaches the skills only required to fulfil course criteria. Students may perform very proficiently in conventional science tests, but have little ability to apply their factual knowledge into investigation work at A’ level (Donnelly *et al*, 1996; Grant, 2011).

The Chartered Institute of Personnel and Development[34] (2014) note that the two most commonly cited factors by those failing to meet career expectations are poor quality careers guidance at school (30%), choosing a wrong career (31%), and a further 28% taking the wrong qualifications. In terms of preparation for a STEM occupation,

Figure 20 (overleaf) shows that over 25% of respondents in 2008/9 felt that their experience of higher education prepared them for career aspirations. However,

[34] In their survey of 2500 employees

the same dataset (not shown) showed that approximately 45% of respondents also considered self–employment, and 42% admitted that they had not felt that their experience had helped them at all.

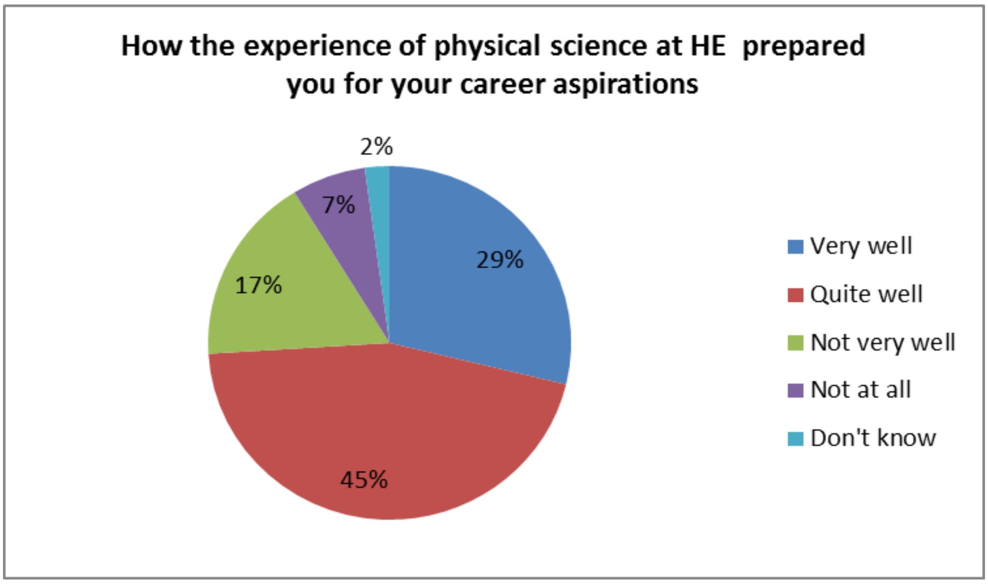

Figure 20: How the experience of physical science at HE prepared you for your career aspirations (Higher Education Statistics Agency, 2012)

Melville argues, "A physics degree does not provide a sufficiently practical approach, commercial awareness and realism… [they] could be improved by giving more attention to applications, innovation and commercial awareness" (2003, p. 141). Amid the claims that degree courses are not developing generalisable skills required by employers (Mellors-Bourne *et al*, 2011; DIUS, 2009; HEFCE, 2009), universities are highlighting the relevance of their physics courses to the wider society. For example, the UCL Physics B.Sc. "aims to go to the cutting edge of technologies that affect everyday life, equipping the student with the tools and imagination to address tomorrow's questions" (University College London, 2012, p. 2).

Universities are also emphasising the inclusion of more general professional skills: Cardiff University highlights that one module is intended "to keep students up-to-date with areas of contemporary physics and to develop skills in communicating physical concepts" (Cardiff University, 2012). A government report (Roberts , 2002) recommended that all science graduates receive 'soft skills' as part of their education. In answer to those recommendations, Research Councils UK distributes funding to universities for professional development and training of skills to make graduates more attractive to potential employers (Hede, 2007). In particular, Research Councils UK aims to ensure researchers are equipped to influence the economy, society and quality of life (2012). The researcher development statement published by Vitae (2010) which designates criteria for researcher skills and emphasises generalisable skills, supports this. These all highlight an awareness by policy makers about the skill shortage concerns voiced by employers.

A report from the UK Commission for Employment and Skills indicates that the supply and demand calculations for 2020, under both the pre-recession and recession states, do not suggest an overall shortage of STEM graduates for the UK. This report however, carefully adds that employers are looking for very specific areas of expertise, but are unable to find specific skills, and from this perspective, the supply of graduates is inadequate. Also noted were the cost-cutting exercises, which have led to some institutions cutting back on experimental work, leading to graduates with less hands-on experience (Bosworth et al, 2013, p. 8). An older report by Mason (1999) also found that the mismatches between supply and demand for STEM graduates “appear to be attributable to quality shortcomings rather than any overall shortfall in quantity” (p. 2).

The need for hands-on skills are considered as a fundamental part of any science degree (Institute of Physics, 2011), and within my research findings, the theme of laboratory skills emerges as a significant influence on the students’ learning journey. It may be that students are misinterpreting the significance of STEM skills demanded by employers compared to the more generalised professional (or ‘soft’) skills. This is discussed further in the finding section in Chapter 4; however, in the next section I examine factors that may influence the decision not to continue with science as a career.

2.10 Education, narrative and identity

McAdams, (1995, 2006) uses the terms ‘storied-self’ or ‘narrative identity’ to describe how a person’s identity can be viewed as an interpretation of their personal experiences (Pals, 2006). This is also referred to as a person's *self-narrative* (Gergen, 1991), as "human actors striv[e] to do things over time" (McAdams, 1993, p. 30). As Tucker-Raymond *et al* describe:

> Identities are built over time. And though still dynamic, they are long-term. More than any one story, we see identities as the accumulations of the daily stories and positioning that result from our daily interactions with others, and change as we gain new experiences. (2007, p. 561)

I am using semi-structured interviews to explore the individuals' reflection of their experiences during their physics degree. These interviews will encourage recollections of the experiences and interactions encountered during the educational journey. It is through these stories and personal narratives (Brown *et al*, 1989); through reflections on school physics through to degree level that I will use to identify the fields of influence during a physics degree and how (if at all) these have modified occupational decisions.

The interviews may allow me some understanding on how the respondents see their relationship with physics. It may be that the educational experiences influence their identity as physics students and aspirations post-graduation. The learning environments (i.e. the institutions) in which students acquire their physics knowledge represents the context. The educational journey is illustrated in the timelines, which are incorporated as part of the discussion in Chapter 4. These timelines map out the historical events identified by the respondents in shaping initial educational decisions, influencing, from the respondents' point of view, the development of their physics student trajectory.

My focus will be on experiences highlighted as significant by the respondents, and I hope to explore whether similar events occur within the educational journeys of the different individuals. I am using only a small reported part of an individual's history to examine their journey through education, so I am not aspiring to isolate the identity of individuals *per se*. My focus remains on the educational events, and the factors of gender, social status, school types, ethnicity and parental background are beyond the remit of my work.

In the next section, I state the main research question and associated sub-questions, in order to proceed to Chapter 3, when I outline my methodology and research plan. I am hoping to get a clearer idea of whether educational experiences during a physics degree are a significant field of influence that affect post-graduation occupational decisions.

2.11 Research questions

Main question

Do the educational experiences on a physics degree play critical part in the field of influences on occupational decisions?

Sub-questions

1. What are the significant influences on the structure of a physics degree?

2. Has school science education been a significant influence on student trajectory into physics?

3. What occupational expectations do students have at the beginning of a physics degree?

4. Do occupational expectations change in light of educational experiences during the degree course?

In the following chapter, I shall endeavour to lay out my research design and methodological stance, in order that the ensuing data analysis and discussion has a theoretical backbone.

CHAPTER 3 METHODOLOGY AND RESEARCH DESIGN

I now intend to outline my methodological stance and the research methods I used in order to answer my research questions.

3.1 METHODOLOGICAL APPROACH

Within the multiple epistemological positions that populate the research literature, I have found myself drawn toward pragmatism, a philosophy founded upon social constructionist theory of knowledge. James (1904) and Dewey's (1920) philosophical pragmatism is founded upon a social constructionist theory of knowledge. This philosophy is seen as a way of understanding the changing world: it tries not to find ultimate answer, but develops understanding through interactions of people and the world. The theoretical stance of pragmatism is not easily defined, but a starting point is the classic pragmatic guideline put forward by Peirce:

> Consider what effects, which might conceivably have practical bearings, we conceive the object of our conception to have. Then, our conception of these effects is the whole of our conception of the object. (1998, p. 146)

This captures a fundamental principle in pragmatism: to use what is known to guide thinking, but to generate knowledge after action and reflection. Pragmatism thus provides the foundation for my case study, as it supports understanding a phenomenon within its context.

I am exploring the educational influences within physics degree courses, so these courses will be my context, and within this context, I aim to understand the phenomena that are the critical incidents and events recollected by my respondents. There will never be any generalisable theory that will emerge from this research; as it is exploratory, I can only think pragmatically about how the experiences of physics degree courses have influenced my respondents. The case study approach means that there is no end theory, no abstraction or idealisation: my focus is not on finding a solution, only clarity in a small part of STEM education.

Dewey's position on pragmatism places it between idealism (reality is mentally constructed) and empiricism (knowledge comes from observation). For Dewey (1910), reality is a self-construction and the sense of reality forms from experience. He argues that life throws us unexpected problems and we must adapt to the ever-changing environments. These uncertain situations provided a stimulus for intelligent action:

> Thinking begins in what fairly enough may be called a forked-road situation, a situation which is ambiguous, which presents a dilemma, which proposes alternatives... In the suspense of uncertainty, we metaphorically climb a tree; we try to find some standpoint from which we may survey additional facts and, getting a more commanding view of the situation, may decide how the facts stand related to one another. (Dewey, 1910, p. 11)

For me a pragmatic approach makes sense, in terms of being able to understand educational experience as a subsection of the memories of lived events. Cremin (1988) emphasises how learning is an intentional factor of education, but learning also occurs through other factors, such as family, religion, media, and nowadays, the Internet. Although I am only focusing on a small section of the educational journey, I hope that the events within this experience will allow me insight into how an individual is influenced by events on a physics degree.

I have also chosen pragmatism as it is a pluralistic approach, and I utilise several different sources of data for a broader context of the educational journeys of my respondents. I examine the institutional prospectuses and interview teaching staff to give a context to the respondents' experiences on the degree. I hope that in examining the different perspectives, I can enhance the context of the interview data.

The use of pragmatism to guide my research also allows there to be the idea of a dynamic goal rather than an end goal. This dynamic goal, to interpret and understand the incidents that influence and shape individuals through time, will guide my research. Thus, as Dewey describes (1938/1991), my goal has substantive meaning for me as a researcher, but remains modifiable as I explore in more depth, and add the experience of others to my own. The next section will examine the concept of critical incidents and their use in identifying the influence on identity and pathways of individuals.

3.2 Design Methods

Following my examination of the literature and destination data outlined in the introduction, I use interview transcripts as my main source of data for analysis. This data allows an exploration of personal experiences encountered along the journey of a degree. My use of qualitative research is as defined by McLeod, in that it is "any kind of research that produces findings not arrived at by means of statistical procedures or other means of qualification" (1994, p. 77). Denzin and Lincoln (1994) describe qualitative research as:

> …multi-method in focus, involving an interpretive, naturalistic approach to its subject matter. This means that qualitative researchers study things in their natural settings, attempting to make sense of or interpret phenomena in terms of the meanings people bring to them. (1994, p. 2)

In the initial planning of my thesis, I examined using a mixed methods approach as described by Creswell and Clark (2011); however, the in-depth quantitative data that I required, to retrace the educational steps of an individual cohort of physics graduates, proved to be difficult for me to obtain. Consequently, I shifted my analysis to examining the current data on destinations as the context for the qualitative analysis, and adapted the research for a case study.

3.3 Case Study approach

Case study research is a popular research method used by social scientists, focusing on understanding dynamics within a single context. Case studies, by their very nature are hard to define, as very different forms of research can be labelled as such (Scholz & Tietje, 2002). I will be using the term, as Yin does, in that it is:

> …an empirical enquiry that investigates a contemporary phenomenon within its real life context, when the boundaries between phenomenon and context are not clearly evident and in which multiple sources of evidence are used. (1994, p. 13)

Yin suggests that case studies are the preferred research strategy when:

> ... the 'how' or 'why' questions are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real life context. (1994, p. 1)

It is worth using a case study for my research because university institutions are complex and numerous, and as I have discussed in Chapter 2, there are numerous studies examining persistence in the science pipeline. This is an exploratory study to examine ten peoples' recollections of their experiences through a physics degree. As Hunter *et al* ((1982) have pointed out, rather than adding yet more empirical data, what is needed is "making sense of the vast amounts of data that have accumulated" (p. 27). It is for that reason that I have chosen to sample two institutions, and within them sample a small number of physics students. I am hoping that the reflective accounts will allow insight into the perceived influences during their educational experiences. I will follow the idea of a holistic case study as set out by Stake:

> [As] shaped by a thoroughly qualitative approach that relies on narrative, phenomenological descriptions. Themes and hypotheses may be important but should remain subordinate to the understanding of the case (1974, p. 8).

In terms of type of case study, my research is a selective case study (Hakim, 1987), focusing only on the experiences of physics students; my objective to contribute a small piece of the jigsaw to the science education pipeline puzzle. I could have decided to survey a larger population of physics students to provide a more generalisable set of results; however, I felt that this was too similar to research undertaken by the Institute of Physics (2010). I also want to include the possibility of finding answers to *why* physics students are not remaining in the physics-related occupations. Thus, my study remains exploratory, with a small sample of interview data providing a richer insight into experiences on the physics degree.

As a form of research, the case study is ideal for considering my research question, as I require a deeper account of the physics degree as recollected by those who have experienced them. To that extent, I have little control over what insights the respondents will give me during the interview. I have formed a semi-structured interview schedule in order to contain the interview to within the parameters of education, but otherwise, the recollected experiences and events are those chosen by the respondents. Within my study, there is obviously little scope for any generalisation, although if similar studies were to be undertaken in the future, and similar results are obtained, there will be a greater possibility for more generalisable statements.

> Once a body of research evidence has been accumulated, particular issues can be focused upon using selective case studies - Other data, provided by other forms of research such as surveys, can be corroborated and illustrated through more richly detailed and precise accounts (Schell, 1992, p. 5).

The process of interview and then coding and recoding of data will begin a process of cyclical research, which "…implies a continuous moving back and forth between the diverse stages of the research project" (Verschuren, 2003, p. 132). This flexibility is a major advantage not shared by surveys and questionnaires. Within my study, the sample size will never qualify for statistical inference, although I am hoping this study will contribute in some way to the literature involved in physics student experience, albeit in a small number of instances. In Table 1 overleaf, I summarise the sources of data used in this research:

Table 1 Final design of case study

	Timelines	**Questionnaires**	**Interviews**
Institutions *Pseudonyms:* Einstein Appleton	Not applicable	Not applicable. Prospectus and website data used.	Not applicable
Undergraduates	6	6	6

Further detail of numbers	*4 Appleton* *2 Einstein*	*4 Appleton* *2 Einstein*	*4 Appleton* *2 Einstein*
Graduates	4	4	4
Further detail of numbers	*2 Appleton* *2 Einstein*	*2 Appleton* *2 Einstein*	*2 Appleton* *2 Einstein*
Teaching staff	Nil	Nil	2
Further detail of numbers			*1 Appleton* *1 Einstein*
Total	**10**	**10**	**12**

3.4 Sampling method

Given the limited number of students in my study, I heeded comments by Pettigrew (1990, p. 275) for my cases have "transparently observable" differences. Thus, I used theoretical sampling to choose my sample. This is in contrast to more traditional, hypothesis-testing studies, which use statistical sampling in order to obtain evidence for distributions within a population. I chose the institutions using the UNISTATS[35] and the Complete University Guide[36] websites. I limited the search field to English institutions and searched by 3-year Batchelor of Science (Hons) physics degree. I excluded all courses with years abroad and sandwich years. This left me with 57 universities in my sample. Due to foreseeable issues with interview timings[37], I then restricted my search area to within 100 miles of Oxford (used as a convenient midpoint for the southern counties and the Midlands), as these institutions would be relatively easy to travel to from the South Coast. This decreased the numbers of institutions to thirty. I then wrote letters (see Appendix A: Letter requesting participation

to faculty heads of university departments identified as having successful physics departments[38], requesting their participation in my research. There were several non-respondents and refusals to participate, but I received positive contact

[35] http://unistats.direct.gov.uk/institutions
[36] http://www.thecompleteuniversityguide.co.uk/
[37] I was limited to school holidays for travelling to institutions to interview
[38] Using the UNISTATS website (2014c).

from five institutions, who accepted my invitation to participate in the research.

From these five, two institutions were then chosen. These two were selected because, although they were not polar opposites, they had several key differences. Using information from the websites and prospectuses, I was informed that Appleton was a Russell group institution with around 15 000 full time students throughout the faculties. It is a collegiate university, spread across a large city. The physics department admits entry to students with an average tariff score of 400[39]. Approximately 20% of staff time is spent on teaching, with 55% on research (these figures have been amended slightly for anonymity reasons).

The other prospectus informed me that Einstein was a non-Russell group institution based in a rural location. It is a campus-based university, also considered to a research-intensive university. It has around 13 000 students, with an average tariff score of 380[2] for admissions into the physics department. No information was given in the prospectus as to the teaching-research ratio of staff.

There were 12 interviews comprising of two staff members, six undergraduates and four graduates. There were five final year students and one first year[40]; I originally wanted to interview final year students as they had experienced most of the course. I also interviewed recent graduates, for their reflections of their whole degree experience including graduation. In some respects, my choice of interviewing current and graduate students was to force a cross-section through time: To complete a longitudinal study of the physics students through the whole of their degree experiences would have been my ideal choice of research method; however, neither time nor funding were available for this option to be viable for me.

I identified potential interview candidates by asking the staff to forward my email request (see Appendix B) for volunteers to their students. The interviewees were a major resource, and my request indicated that I was looking for people who were committed to physics. In doing this, I was hoping for individuals committed to their subject, who might show a similar intellectual commitment to my research

[39] Average tariff scores are calculated using the UCAS tariff points system, where A-level tariff scores are A*=140, A=120, B=100, C=80, D=60, E=40.

[40]There is further justification for the inclusion of the first year on page 63.

project[41]. My request for volunteers resulted in somewhat more responses than anticipated[42]. I was limited in amount of time available for interviewing and transcribing data, thus I was forced to select a sample from my prospective volunteers. I tried to ensure a representative sample of students, in terms of age, gender and background, although due to the limitations of online communication, I could not use any in-depth background information.

The graduates' request was sent out through a variety of social media platforms, including LinkedIn and the alumni mailing list from each institution. By utilising these more external forms of communication, I hoped to minimise any possibility of a skewed dataset; as Cohen *et al* (2011, p. 159) point out "[snowball sampling] can be prone to the biases of the influence of the initial contact"; (i.e. where the individuals were chosen because, for example, of their relationship with staff or lecturers). This also provided me with access to graduates who had entered the job market and not just within the institution completing further study. This gave me opportunity to explore what employment they were in, and their reflections on why they had entered it.

3.41 Questionnaires and Timelines

Each interview started with an introduction to my research and a pre-questionnaire (see Appendix D). This questionnaire was piloted by the doctoral students on the Doctorate of Education and Social Work workshop weekend. Feedback, including question wording and ambiguities, were ironed out prior to the pilot study.

Prior to the interviews, I explained both the questionnaire and timeline to the respondents. This was done either during face-to-face interviews, or during a Skype

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[41] This opens me up to criticisms of researcher bias, however in terms of exploring what experiences can influence physics students to identify with their subject and remain in physics-related employment, I also felt that these individuals would have similar values and so would give consistent narrations about their experiences. I did not want individuals who had already rejected the subject, but individuals who loved the subject and would rich descriptions of their experiences on the course

[42] In total, I received around 55 replies.

correspondence, the interviewees were given some time alone to complete the questionnaire and the timeline before the interview began.

The questionnaires were designed to give the interviewee some time for self-reflection prior to the interview process. Initial questions asked respondents to provide basic demographic information and educational background and to consider aspects of their education, parental employment and exam results. This was used as a memory jogger for remembering key aspects of education history. The questionnaire also included self-assessment questions[43], where respondents rated their enjoyment and ability in a range of different activities. These were included to encourage the respondent's self-reflection, an issue I considered vital for the success of the interview.

Following the questionnaire, but prior to the interview, respondents completed a timeline of incidents and events that they considered important during their educational journey (see Appendix E: Timeline). After explaining the structure of the diagram, I left them some time in private to complete the timeline as they saw fit. For those who were interviewed over the phone or by Skype, I sent them the diagram prior to the interview. I wanted them to include any remembered events as these, to some degree, are those that with hindsight may become critical in identity trajectory. Following the interview, the respondents revisited their timeline and added to it on reflection of their narratives.

3.42 Student sample

The sample of physics undergraduates consisted of six individuals from the two institutions. Two were final year undergraduates from Einstein and three were final year undergraduates from Appleton. One undergraduate was a first year from Appleton, added as a unit for comparison. Within the current students, there were four males and two females. The sample of graduates included two graduates from Einstein and two graduates from Appleton. The gender ratio in this sample was three

[43] I have used similar questions in my lessons when completing action research for the science learning centre in 2009 (Rietdijk, Grace, & Garrett, 2011)

male to one female. All the interviews were completed between February and June 2014.

The following table explains the pseudonyms used for the student respondents:

- The precursor A or E identifies the institutions as either Appleton (A) or E (Einstein)
- The numeral 1 or 2 identifies the individual as either undergraduate (1) or graduate (2)
- The next two letters identify the individual's code
- The final letter F or M identifies the respondent as female (F) or male (M)

I also interviewed a member of staff from both institutions (pseudonyms AXTS and EXTS). In this sample, both the interviewees were male and no further background information was requested from them, as their input about the courses was only necessary for contextualising student responses. .

Table 2: Summary table of interview sample

Institution	**Identifier**	**Gender**	**Occupation as of June 2014**	**Interview process**
Appleton	A1AMF	F	Student	In person
	A1ASF	F	Student	SKYPE
	A1OBM	M	Student	In person
	A1PTM	M	Student	In person
	A2CCF	F	Graduate/ Education	SKYPE
	A2TGM	M	Graduate/IT	SKYPE
Einstein	E1BCM	M	Student	SKYPE
	E1NFM	M	Student	In person
	E2CPM	M	Graduate/IT	SKYPE
	E2NSM	M	Postgraduate/ Education	SKYPE

The interviews took a semi-structured form and were carried out on an individual basis, whether in person or through Skype. The interview schedule was designed so that I could follow how individuals made sense of their lives in the context of family, school and university. They were semi-structured to ensure that the topics I was interested in were covered, in a relatively broad and flexible way (Denzin & Lincoln, 1994). The interview schedule (see Appendix F) formed the framework for the interview, including questions that tracked the journey through education. The same schedule was used for every interview to ensure that each respondent was probed in a consistent and systematic manner. Additional probes were included on the questionnaire designed to elicit responses that were more detailed. Because the interview was semi-structured, I could override the schedule whenever the area being discussed seemed to have more detail than was apparent in the respondent's initial answer. It was for this reason that the semi-structured approach was chosen, as it had flexibility to allow interviewees to bring up relevant areas, allowed my deeper exploration, and was rooted in conversation. This conversational aspect encouraged the interviewee to feel comfortable in discussing their past in an interactive manner.

Interviewing requires "a respect for and curiosity about what people say, and a systematic effort to really hear and understand what people tell you" (Rubin & Rubin, 1995, p. 17). I have acknowledged that in using interviews as a source of my primary data, I am using data that can be considered a social construction, created by my respondents and whatever interactional cues have been given by me about their accounts. However, it is fair to say that this is a critique of all interviews (Dingwall, 1997, p. 59), and as a consequence, I have been proactive in encouraging the revelation of authentic experiences by allowing myself to listen to their accounts before probing deeper when significant incidents were hinted at. Rapport was considered paramount, and for that, I referred to the works of Douglas (1985). A more in-depth breakdown of my interview schedule is described later in this chapter.

In all the interviews, I tried to ensure that the social setting was conducive to the respondent being audiotaped. I also tried to ensure that the situation was arranged so that the interviewee felt at ease to speak openly. I have read some of the discourse on Foucault's (1980) view of power and knowledge in social inquiry and so respected the interview process could be viewed as a method for control. With this in mind, I allowed each interviewee some time for asking me questions about my research question. To each of them, I answered honestly, but without giving any of my hunches away; in fact my aim was to ensure that I was as genuine and personable as possible in what was otherwise quite a contrived situation. Although it is clear that, in the postmodern age, an interview really has become a means of contemporary story-telling (Gubrium & Holstein, 1997). In no case did I assume that the respondents would always provide complete and accurate accounts of their history, and I undertook the interviews fully aware that failing memory and time passing might be enough to skew any interview data.

All the interviews were transcribed verbatim, with my analysis using the transcripts as an accurate reproduction of the participants' words. The respondents were given the opportunity to crosscheck their individual transcriptions, check the contents and determine the extent to which they reflected their experiences. Although given this opportunity, no respondents chose to alter the transcripts.

The interviewees were central to my analysis as they represented the two institutional case studies. They were a primary source of data about the experiences of a degree course, so gathering a rich description during the interview was vital. The two lecturers were interviewed to gain an internal overview of the physics courses that were separate, and more insightful than the online prospectuses. I interviewed the lecturers using the same schedule as the students, but adjusted the questioning so the respondents described their own views and expectations of the students learning experiences during the degree course. They provided me with an additional interpretation of the significance of taking a physics degree and their own expectations for physics graduates. These interviews explored what they considered to be the important factors of the degree and how authentic science was incorporated into the courses.

Questioning began by focusing on experiences of secondary school science lessons, and what aspects of this (if any) influenced decisions to take a physics degree. The interviews that I conducted incorporated questions that revolved around six topics that were then analysed post-interview for emergent themes. The topics that were covered during the interview were:

- The influences that led to their choice of degree
- The influences that led to the choice of university
- Aspects of their degree course
- The expectations of themselves, the course
- Their future aspirations before, during and after
- Memorable incidents encountered during the university experience

The questions on the interview schedule were adapted from Kvale's (1996, pp. 133-35) typography of questions, which were divided into a fairly neutral beginning to encourage collaboration in my research, then becoming more in-depth, thus tracking outlined themes. I explored student expectations at initial enrolment and how these changed over the duration of the course. To some extent, subtle events occurring during their experience of education had informed expectations for occupational destination, and the interviews were designed to allow the respondents to reflect on those things occurring during their degree that they deemed as significant influences. Some of these were considered critical enough to sway final decisions about post-graduation occupations.

I interviewed final year undergraduates to find out what their expectations were when they applied and how this compared with their experience over the course duration. The interview was looking to identify the events that they recalled over their education and degree course that they felt had influenced their post-graduation destination. The graduates were all slightly older than the undergraduates were, but the ages were within a maximum of 30 years old: the intention was to ensure that major life events had not overtaken and overwritten memories of their degree years. Within the final analysis of the data, I was then hoping to identify any common themes between the different experiences of the undergraduate and graduates.

The interview narratives were formed from the interview transcripts. The preliminary questions were used as memory joggers, a way of building on the questionnaires that served as a gateway to historical educational experiences. This was my exploratory phase of the interview, with questions probing the multitude of directions towards decision- shaping incidents. This ensured that the respondents started with a concrete description of an event, and thereafter the probing questions focused on the detail; an analogy similar to photographic enlargement, whereas my probing deepened, I got less overview of the wider picture, but a more detail view of the respondent's educational journey.

It was evident during several interviews that the respondents' self-reflection had led to a re-evaluation of what had initially seemed like small insignificant events. There seemed to be, on occasion, a new view of 'self' emerging as our discussion opened up transforming ideas. For me, it was those subtle surprises that were interesting. As Hudson writes:

> It is important to recognise the features that we have unconsciously espoused or constructed for ourselves and those we have taken from, or have been imposed by others, or which are embedded in certain ideas or practices that we have adopted.
>
> (1972, p. 114)

I also used other sources of primary and secondary data for my analysis. The prospectuses from the institutions were downloaded from their online sources, and converted into document formats. These documents provided information about the course structure, course content, assessment methods and expected student workload[44]. These were inputted into NVivo, along with completed timelines. The preliminary questionnaire data was summarised into a Microsoft Excel spreadsheet, and imported into NVivo. Each interview (both phone, Skype and face-to-face) was transcribed into a Microsoft Word format and inputted into NVivo. This data was then read carefully, and similarities and differences between different participants were carefully noted. All the material was then classified and coded thematically.

[44] They also provided some insight into the advertising methods used to encourage potential students, as described at the beginning of this chapter (page 52)

3.43 RESEARCH ETHICS

As previously discussed, I am using case study to examine two institutions. Using these cases, I am hoping the data collection will provide the details for an in-depth analysis, which in turn will offer insights into the nature of a physics degree. As my study is exploratory, I have no preconceptions about the journey that respondents may describe in interview. Although it is under the interview mantle, the respondents will have freedom to illustrate their story in a non-deterministic way that guides me through their educational story. This narrative will be a representation of themselves and how they make sense from their lives. This method of narrative raises some issues in terms of informed consent for the interviewees. Within the remit of my ethics review[45], I considered four major ethical issues as described by Dicicco-Bloom and Crabtree (2006, p. 319):

- effectively informing interviewees about the nature of the study
- reducing the risk of unanticipated harm
- protecting the interviewees information
- reducing the risk of exploitation

I addressed these ethical considerations by initially seeking participation from institutions and departments to run my research through letter[46]. I also sought permission from undergraduates and graduates and in several instances; I sought further permission to use the timelines within my appendices. All the institutions and volunteers were given an information sheet[47], informing them about the nature of my study. Hammersley (2014, p. 538) warns against the possible gaps between interviewee expectations about how their story will be told and how researchers interpret what they say. To negate this possible discrepancy, the volunteers were given a brief summary of my research outline in the information sheet. This research outline may not have been as much as demanded by Shils (1980, p. 429), where "questions ought to be justified by the explanation of what [the] answers will

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[45] University of Sussex Social Sciences & Arts Cross-School Research Ethics Committee CERTIFICATE OF APPROVAL Reference ER/AJH52/1

[46] See Appendix A

[47] See appendix C

contribute to […]" but equally, it provided the interviewees with my research focus. The final coding of the data with the resultant emergent themes was not incorporated in this outline. As indicated by Hammersley, there must always be a degree of deceit within interviews, as giving fully informed consent prior to the coding is significantly problematic and could influence what the interviewees chose to share with me. I asked for written consent from every respondent and, immediately prior to the interview, I asked for verbal consent, and offered the option of ending the interview at any time if required.

In terms of protecting the interviewees' information, I have ensured complete anonymity of results (by both institution and individual) by using pseudonyms. I was aware of the slim chance that this work could uncover issues with university physics degrees that could potentially be misrepresented by third parties. Although my use of case studies does not allow for generalisation, it is a possibility that negative feedback could result in a negative impact on those who were extremely helpful in my research. Thus, it was imperative that only issues and not names are identifiable.

3.44 Pilot interviews

Prior to conducting the interviews, I studied the literature in performing and interpreting interviews. I acknowledged that an interview is a complex interaction, and not guaranteed to reveal any truths about external reality (Alvesson, 2010, p. 27). Charmaz (2002, p. 317) assumes that questions and interviewing style "shape the context frame and content of the study." She highlights how framing the questions takes "skill and practice" and warns against asking the wrong questions, stressing the need to ask questions that "both explore the interviewer's topic and fit into the participant's experience" (2002, p. 315). Thus, although I could not completely control all external factors, I took into account that the interview would be a contrived conversation between the respondents and me.

There is always the possibility within an interview that there are equally valid but very different accounts from differing perspectives (Maxwell, 1992, p. 284). It is worth remembering that the interviewee may not communicate exactly to provide perfect data. However, in this respect, my view is that my respondents had volunteered for interviewing: there had been no coercion, and thus I made an assumption they were participating due to their own interest in physics.

In terms of the ability to articulate thoughts, several studies have identified that education and class matter to interview quality. My favourite argument of this thesis remains Alvesson articulating that the higher the level of education, the more skilful people are with words, whereas for the less educated, the people may be smarter than their words (2010). I had some uncertainty about the quality of reflection that I would glean from physicists, however, my stereotyping of mathematically-minded theoreticians fortunately proved to be unfounded.

Shensul *et al* (1999) suggest that there needs to be a flow of interaction between interviewee and interviewer to ensure interview quality. It was a steep learning curve during my pilot interviews to avoid disruption to the flow by my interruption, and thence learning how to use non-verbal cues successfully. Using a preliminary interview guide, I conducted pilot interviews with two volunteer undergraduates. Based on these pilots, I modified the guide to improve the flow of the questions and altered the structure to prevent leading questions, but otherwise I did not change the content, only my technique. I followed Roulston's (2010) advice on pilot interviews, ensuring that my interview was rehearsed, piloted twice and then a further time when I videotaped myself as the interviewer and made amendments to my body language. I found that my main weakness was finishing sentences for the respondent: consequently, I practised (with my peers and pupils) waiting for a considerable time for an answer to questions. Consequently, by the time my first interview arrived, I felt prepared in such a way that I was free to focus solely on the respondent and their answers.

3.5 Research questions revisited

Human experience can be communicated through a narrative: "when persons note something of their experience, either to themselves or to others, they do so not by the mere recording of experience over time, but in storied form" (Clandinin & Connelly, 1998, p. 154). Polkinghorne (1995) outlines the two modes of analysis: 'analysis of narrative', which attempts to identify common themes across a series of narratives, and 'narrative analysis', which embraces the epistemological stance of narrative cognition, to analyse the narrative on its own terms. For my purposes, I will be using an analysis of narrative to examine the interview transcripts and utilise thematic analysis in constructing themes from the ideas that emerge. On the following page, I will revisit each sub-question to summarise how I will go about answering each one.

1. *What are the significant influences of the structure of a physics degree?*

To answer this question I will start with an examination of the prospectuses of the two institutions, and use the NVivo qualitative analysis software to identify any common themes in course content and structure. Most prospectuses are available online and are easily downloadable. Although the increasing specialisation was identified in my critical analytic study (Holmes, 2013) as one factor in the changing nature of science, the variety of physics courses are too numerous to separate successfully. Thus, I focus on three-year Batchelor of Science, Physics degree courses, whilst remaining aware that many such courses are becoming four-year Masters Courses. I will then examine the interview data from the teaching staff to get some idea of the 'lived' experience on a physics degree, compared to the 'marketed idea.'

2. *Has school science education been a significant influence on student trajectory into physics?*

3. *What occupational expectations do students have at the beginning of a physics degree?*

4. *Have the educational experiences on the physics degree been influential in these changes?*

In order to answer the three sub-questions, I will interview the undergraduate and graduate students to gain clarity on the experiences of the respondents. I will also use their timelines to gain insight into how the respondents identify their own education as a journey. This will enable my data to reflect the complex and contextual portrayal of real life from the different individuals. The diagram shown on the next page summarises the whole research design, including each sub-question and the method used for each stage.

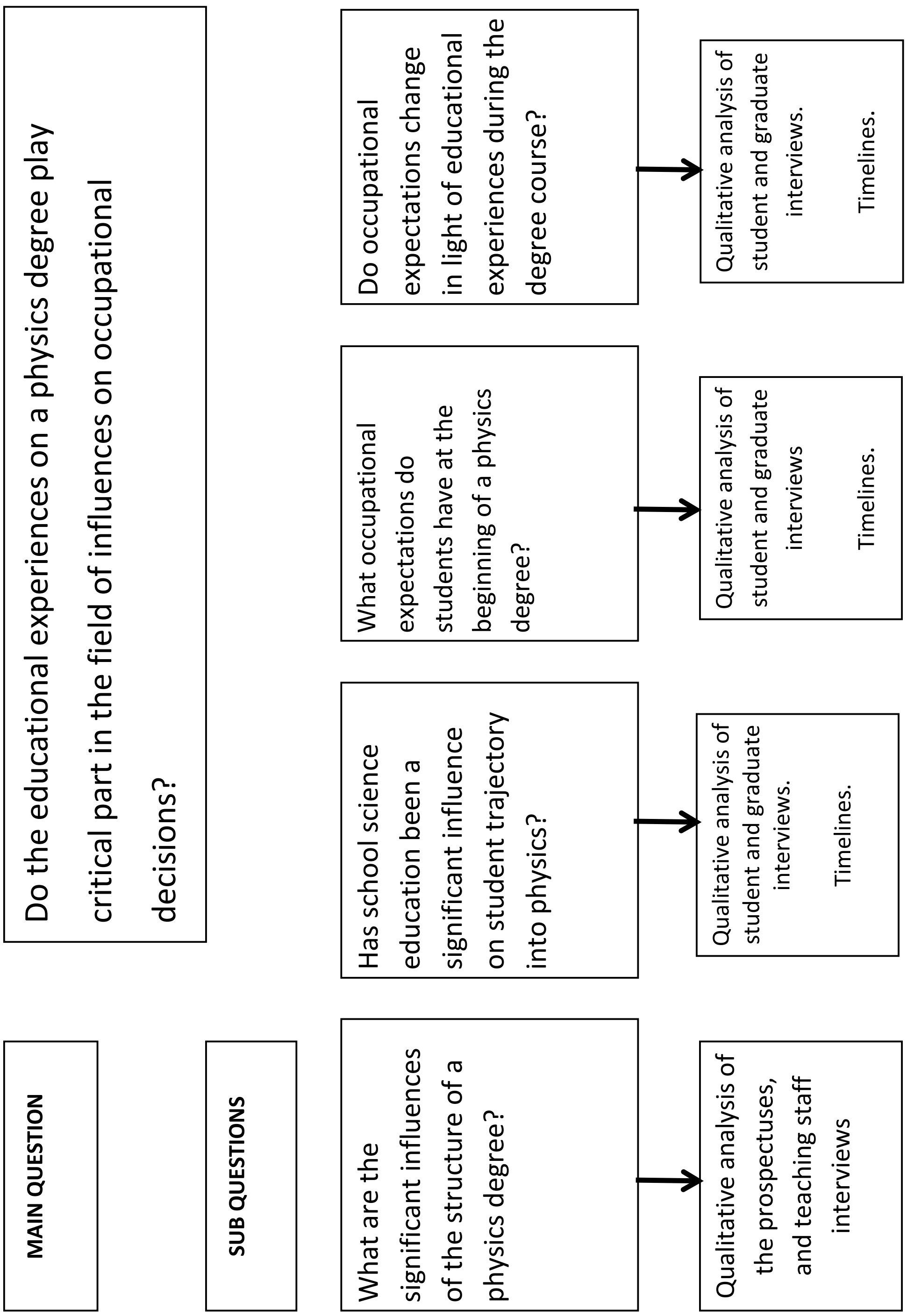

Figure 21: Summary of the research design and methods.

3.6 CRITICAL INCIDENTS IN FIELDS OF INFLUENCE

I am exploring the educational experiences as one factor in the field of influences for individuals on a physics degree. For this, I am going to use the concept of critical incidents to identify events deemed significant to the ongoing development of the scientific identity. Critical incident technique is a way of collecting, analysing and classifying human behaviour, allowing insight into phenomena that are not well-documented (Gremler, 2004). There is little reference in the literature to educational experiences of physics students, thus I will use the technique as a basis for analysing the interview data: to explore the events that my respondents reflect on being important during their physics degree experience. Flanagan (1954, p. 338) describes an incident as "critical if it makes a significant contribution either positively or negatively to the general aim of an activity." These incidents determine whether an individual leaves a situation satisfied or dissatisfied. I will use this concept to explore the negative and positive events within the field of influences, perceived to be significant by the respondents (Edvardsson & Roos, 2001).

It has been 60 years since Flanagan (1954) wrote his classic article on the critical incident technique. Since then, this technique has become a widely used qualitative research method[48] and today is recognised as an effective exploratory and investigative tool (Woolsey, 1986). Flanagan stated the critical incident technique as something that:

> ... does not consist of a single rigid set of rules governing such data collection. Rather it should be thought of as a flexible set of principles that must be modified and adapted to meet the specific situation at hand (1954, p. 335).

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[48] When surveying the critical incident literature for my research, it became evident that the terminology is inconsistent, even amongst those that are clearly following Flanagan's method. For instance, the terms critical incident analysis (Gould, 1999); critical event technique (Kunak, 1989); critical incidents technique (Schwab, Heneman, & DeCotiis, 1975); critical incident exercise (Rutman, 1996); critical incidents (Pope & Vetter, 1992); and critical incident reflection (Francis, 1995) all use critical incidents as the basis for analysis.

In the original version of the technique, Flanagan (1954) described it as having five major steps:

i. Focus on the general aims of the activity;
ii. Plans and specifying the direction of research;
iii. Collecting data;
iv. Analysing data;
v. Interpreting and reporting

(1954, pp. 336-345).

The primary use of the critical incident theory produced by Flanagan is a tool to describe the educational events from a broad base of interview transcripts and narrow them down through data analysis. This ties up with my use of pragmatism, in that I have identified the phenomena and gradually narrow my focus onto the themes that emerge through analysis. I will the significant events, i.e. critical incidents, over the course of the physics degree are, that have perceived as such by the respondents.

Tripp (2011) argues that there are two stages in critical incident creation: an observed phenomenon leads to a description of what happened to make the event notable. Tripp calls this the production of an incident, explained within the context of the individual's experiences. The incident becomes critical, when on reflection it is marked as having made a significant alteration in an individual's life journey. It is important to emphasise that critical incidents are not things that exist independently of an observer and await discovery, but are created through the interpretation of a situation:

> To take something as a critical incident is a value judgement we make and the basis of that judgement is the significance we attach to the meaning if the incident...In principle, we can read any and everything that happens in a critical fashion (Tripp, 1993, p. 8).

To turn the event into a critical incident, he argues that it must be taken in context, such that both the cause and event need analysis. It is important to note that the vast majority of critical incidents are not dramatic, but mostly straightforward accounts of commonplace events that occur during daily life. They will become critical if they are indicative of an underlying trend during different individuals' experiences of their degree course. As Tripp says, incidents may appear to be typical rather than critical at first sight, but are rendered critical through analysis (1993, p. 24).

Gremler (2004) points out that research into critical incidents is flexible so can be adapted to any particular research situation. Hence, in the context of this study, an incident will be described as either a positive or a negative event that is particularly memorable, and leads to a decision that affects the individual's pathway. My analysis will look for trends beneath these events that involve similar significance across the different individuals from different institutions. I hope to find out whether there are significant events that traverse the different respondents within the same context of the physics degree in order to answer my research question.

Although critical incident theory is a qualitative research method, it was initially posed as a scientific tool to help uncover existing realities such that they could then be quantitatively measured. For my purposes, I will not be trying to quantify the results for such a small sample. Within the remit of critical incidents, I will be following the structure as put forward by Butterfield et al (2005, p. 483), who have described the distinctive features as:

(a) *Focus on critical events, incidents, or factors that help promote or detract from the effective performance of some activity or the experience of a specific situation or event*. My focus will be looking at whether incidents on a physics degree influence the individuals towards or away from physics occupations.

(c) *Data collection is primarily through interviews, either in person or via telephone.* Although there is more discussion of method in the following chapter, the main data collection is through interviews, both in person and Skype.

(d) *Data analysis is conducted by determining the frame of reference, forming categories that emerge from the data, and determining the specificity or generality of the categories*. My semi-structured interview determines my frame of reference, with my themes emerging from the analysis during coding.

(e) *Narrative form is that of categories with operational definitions and self-descriptive titles.* As it is coded, I will analyse the transcripts for emerging themes, thus the categories are operational as opposed to theoretical.

There are various methods for checking credibility described in the literature for critical incident theory, such as independent researcher cross-referencing and recoding, second interview crosschecking and interview fidelity (Gremler, 2004). My study has been completed as part of my Doctorate of Education, and as such, I remain a lone researcher, with little access to other researchers willing to dedicate their time to recoding or crosschecking my data. However, with my acknowledgement of these limitations, I would hope that any similar studies in the future would include more rigorous crosschecking and recoding by independent researchers. I can argue that my work remains valid; as Hammersley and Atkinson state because "data in themselves cannot be valid or invalid; what is at issue are the inferences drawn from them" (1983, p. 191). It remains inherently possible that other researchers could identify significance differences in their interpretation of the interview transcripts. Saying this, however, within the discussion of the results in Chapter 4, I have endeavoured to include as much of the transcript *verbatim*, allowing the reader to consider the process by which the themes have emerged from the interview data.

There are limitations from a methodological point of view, as historical events can be lost or reconstructed from memory; as such, historical recollections are plagued with reliability and validity problems (McAdams, 1993). As data, critical incidents are minute fragments of the complexity of life experience, uncorroborated at the time and reconstructed long after, but Maxwell (1992), like Hammersley and Atkinson (1983), posits that understanding is more fundamental than validity[49]:

> The applicability of the concept of validity presented here does not depend on the existence of some absolute truth or reality to which an account can be compared, but only on the fact that there exist ways of assessing accounts that do not depend entirely on features of the account itself, but in some way relate to those things that

[49] Maxwell uses the term validity in a broad sense, relating to the relationship between an account and something outside of that account.

> the account claims to be about and from that perspective, I must assume that the respondents are giving an honest narrative of their experiences (1992, p. 283).

During the interview process, it was evident that there were events that were significant to the respondents. Tripp (1993) has written substantially on the use of autobiographical critical incidents, citing how they are easily recalled for two reasons: they have an unusually high emotional charge together with a continuing significance. He describes those which remains locked in memory in spite of other experiences, together those that are frequently recounted stories that renew memory with every telling. They become, in all respects:

> ...war stories that are used to illustrate favourite points that we are making or just to remind ourselves of particular categories of experience, things we should or should not do, things that were fun or successful, that are quintessential in one way or another (Tripp, 2011, p. 97).

It is the respondents' perception of their experiences that will determine if the event has been critical in term of their educational journey: possibly no more than a small event perceived as a nudge in an altered direction. I intend to approach critical incidents in a similar way as used by Le Mare and Sohbat (2002) and by Angelides and Ainscow (2000), whereupon educational experiences are discussed during interview and the critical nature identified and interpreted during the analysis. This interpretation will be assisted by including the respondents' timelines where they noted significant incidents.

3.61 Thematic Analysis

LeCompte explains the nature of qualitative data as:

> Because [qualitative] data have no initial intrinsic organizational structure or meaning by which to explain the events under study, researchers…must then create a structure and impose it on the data. The structure is created in stages, and forms the basis for assembling data into an explanation or solution. Creating the structure is analogous to the strategies used to assemble puzzle pieces; the pieces are like units of analysis in

the data. (LeCompte, 2000, pp. 147-48)

As my study is exploratory in nature, my data has included several different sources. My main analysis focuses what I consider my main source of data: the audiotaped, in-depth interviews with the students. The transcribed interviews were analysed in NVivo using thematic analysis method (Boyatzis, 1998). For Boyatzis, thematic analysis functions as:

i. a way of seeing;
ii. a way of making sense of seemingly unrelated material;
iii. a way of analysing qualitative information;
iv. a way of systematically observing a person, an interaction, a group, a situation, an organization, or a culture; and,
v. a way of converting qualitative information into quantitative data

(1998, pp. 4-5).

I chose thematic analysis because it allowed me to identify patterns in the interview transcripts. These patterns pave the way for my subsequent interpretation of the emerging themes in the data. This data-driven approach was adopted because I did not anticipate my findings fitting into a specific theory; instead, my aim was to explore the reflections about educational experiences on the physics degree.

Thematic analysis is commonly used to identify and analyse data for meanings produced by people, situations and events (Boyatzis, 1998; Braun & Clarke, 2006; Patton, 2002). In contrast to other methods, thematic analysis does not require a pre-existing theoretical framework; it can be used across the different frameworks of essentialism, realism or constructionism (Braun & Clarke, 2006). More importantly for my work, I can use it to identify how individuals make meaning out of their experiences and how their social context impinges on those meanings. Therefore, Braun and Clarke describe it as “a method that works both to reflect reality and to unpick or unravel the surface of ‘reality’” (2006, p. 81). They describe themes as “captur[ing] something important ... and represent[ing] ... a patterned response or meaning within the data set” (2006, p. 82). For them, it is evident that there is no correct answer when it comes to coding themes.

I identified my themes through inductive coding; although the data was collected specifically for research into student experience through education, the themes only bear subtle reference to the interview questions. The significance of my themes was not wholly determined by the frequency but by the "substantive significance" (Patton, 2002, p. 467). This refers to the consistency of themes across and within the interview data: as I analysed the transcripts I was aware themes emerging relating to the developing science identities of the students. These emergent themes included the changing perceptions of physics, feedback on work completed, and laboratory work as part of the field of influences on the respondents.

The coding is inductive because I rely on the "study of a range of individual cases and extrapolates patterns from them to form a conceptual category" (Charmaz, 2006, p. 188). I have used systematic coding for reliability: as thematic analysis does not produce statistical tests of significance, my themes are significant because they emerged from the interview transcripts from each respondent and were confirmed using concepts identified in the literature on identity and trajectories. I looked understand how the educational experiences formed part of the field of influences by looking for repeated patterns of meaning: thus the themes were formed inductively from recurrent events: as Boyatzis describes "the most basic segment or element of the raw data or information that can be assessed in a meaningful way regarding the phenomenon" (1998, p. 63).

Following the steps outlined by Braun and Clarke (2006), in the first stages of analysis, I read and re-read the data to generate initial thoughts on the content. The information was embedded within the interviewee responses rather than abstract statements, so I had to tease this out through discrete coding: thus, the codes were not developed based on questions asked, but by the nature of the responses given. Codes were initially added for the different ideas and images that emerged from the text: with no preconceived codes, each new code referenced a discrete idea not previously raised. Initial coding included terms such as 'school education', 'teachers,' 'teaching', 'memorable events', and 'enjoyment' as some examples. Interviewees often made several points in the same sentence, and so each was separately coded.

Information was sometimes given as answer to direct questioning, but it was also offered as comment, within narrative, and as illustration to making a point.

When I had coded and recoded several times, I then looked to collapse the codes into larger categories: 200 codes became 150, which was then recoded and re-amalgamated. Eventually, this process allowed the codes to condense into main themes, fewer sub-themes and a very few deletions.

My coding looked for themes that ran through the prospectus, staff and student/graduate interviews. In analysing the graduate interviews, I looked for incidents that tied up with the undergraduates. I was aware of potential problems in trying to link up ideas through the undergraduates and graduates in order to form my 'snapshot'; potential problems of continuity could have included recently changed course structure or staff. However, it was never my intention to identify individuals, only the fields of influence in their experiences along the educational journey.

3.62 Student interview analysis

Following the coding and amalgamation to identify emergent themes, I recognised that my interview schedule had covered several topics, but new themes had emerged that spanned both undergraduates and graduates across both institutions. My analysis started to find patterns in the discussions of different experiences. I revisited the idea of identity construction as a dynamic process (Holland *et al*, 1998; Giddens, 1991), where individuals' conceptual view about themselves shifts as they develop new understandings based on new experiences.

As previously discussed on page 30, using the concept of identity as a form of motion assisted my interpretation of what experiences[50] were influencing the respondents' identity as a physicist, scientist or neither. Experiences led to shifts in their procedural identity, where it became obvious that if they were inspired, they increased participation, and if not, they invested in a new direction. To all purposes, inspiring experiences would have initially influenced the respondents to engage with

[50] The field of influences.

physics; however, I used their reflections to examine what inspiring events from an educational perspective had been influential.

The subsequent themes remain my interpretation of how the respondents' identity has been shaped their educational experiences as a part of the field of influences. As such, I recognise a major limitation is in my interpretation of how the interviewees conceptualise their 'self' through their reflections of their educational journey. In analysing the interview transcripts, I understand how my own theoretical insights and interests inevitably will influence the interpretation; however, despite this limitation, the interview transcripts provide some useful insights into student reflections of their educational journey and experiences.

3.7 Reflections on methodology

In an ideal world, I would have completed my research over a long time and tracked a single cohort of students through their complete educational journey. This would have provided me with many observations over a period of years, allowing me to observe the field of influences surrounding decisions to enter and remain in physics. Weaknesses of such a longitudinal study however, include the requirement for more time than is available to me, and substantially more cost. Additionally, there would be no guarantee that individuals choosing separate sciences in school would eventually enter physics-related employment, and as my sample numbers diminished, whatever representativeness I had established in the initial sample would be lost (Douglas, 1976). Thus, due to the limitations of time and funding, I chose my retrospective study to explore the field of influences surrounding student decisions to enter physics-related occupations. In choosing to interview both current and recently graduated physics students, I am obtaining a sample snapshot of educational journeys during and after physics degree courses.

There are significant weaknesses with this approach however. The reliance on using remembered information for my main source of qualitative data leaves my findings open to inaccuracy. Memories can be re-interpreted in light of subsequent life events, and people can also be highly selective in remembering past experience

(Marshall & Rossman, 2010). However, as I am interviewing people still within and recently graduated from, the degree course, I am hoping that their memories are not too distant to recall the significant events they have experienced. Their stories told during the interview process will still broaden my understanding of the experiences they wish to share regarding their own life history:

> When people tell stories, they select details of their experience from their stream of consciousness. . . . It is this process of selecting constitutive details of experience, reflecting on them, giving them order, and thereby making sense of them that makes telling stories a meaning-making experience (Seidman, 2006, p. 7).

The small sample means that the findings are only directly applicable to those from the universities involved, but even a small sample will contribute some new knowledge to the field of STEM education. I am not aiming to generalise my results: my aim is "concerned with providing analyses that meet the criteria of unique adequacy" (Psathas, 1995, p. 50), and "to provide an analysis uniquely adequate for that particular phenomenon" (p. 51).

During the coding and thematic analysis, I was aware of the emerging saturation[51], as described by Glaser and Strauss's (1967) account of grounded theory. As I interviewed quite a homogenous group of people (people completing physics degrees) and my research is quite tightly focused on the educational experiences, the analysis reflects Guest *et al*'s (2006) findings that saturation can be attained even through twelve interviews. I am following Mason's advice:

> It is better to have a smaller number of interviews, creatively and interpretively analysed, than a larger number where the researcher runs out of time to do them justice analytically. It is better to aim to offer sound qualitative insights, than try to mimic a quantitative 'representative' logic (2012, p. 29).

[51] Theoretical saturation is described as a process in which the researcher continues to sample relevant cases until no new theoretical insights are being gleaned from the data

With that in mind, the next chapter will examine the themes that emerged through analysis of the 12 interviews, and how these relate to the field of influences evident during the educational journey of the interviewees.

Chapter 4 Research Findings

4.1 Theme 1: influences on engaging with physics

4.11 Non-educational influences

During the analysis, it was evident that many of the respondents had acquired an interest in science at an early age. During the coding process, differences in how the respondents went about choosing their A' level options emerged and are discussed below. The emergent theme highlighted the importance of family and the media as early influences for interest in physics:

E1BCM: My dad was an electrical engineer, and he brought his work home a little bit and was always very happy to answer my questions… as early as I can remember, I always wanted to know what was going on around me and I kept on going.

E1NFM: I used to read New Scientist as a kid. I always enjoyed that... My granddad was big into that – physics was one of the things he was fascinated by.

E2NSM: And doing a bit of work experience with my physics teacher, which was more or less running round breaking open things and figuring out how they worked.

A2TGM: I was more interested in the mathsy side really. So through maths, also 'big science' like astronomy and the big news things like the LHC and stuff like that, space, time and general relativity.

A1OBM: I think from that rough science programme I did like the idea of my being something of a scientist but it was never so much as a clear ambition.

A1PTM: But my main interest in physics came actually not from school, but from reading science books and reading stuff about things like the Large Hadron Collider in the news.

*A2CCF: So he [*family friend*] would give me papers to read, really articles from Nature or Science he'd found, and then just talk to me about it, humour me on it.*

These correlate with the previous quantitative data from the Wellcome Trust (Clemence, et al., 2013), previously discussed in Chapter 2 (Section 2.5, pp 38-9), that the initial formation of interest and initial identification with physics occur through external influences, such as parents and friends, as well as the media.

4.12 Influence of educational attainment

Four of the respondents (two undergraduates and two graduates) reflected on how their high school mathematics ability allowed them to consider physics as an option, while two respondents from Appleton also remembered feeling surprise at their school mathematical ability:

A2TGM: I suddenly realised I was good at maths originally, or to a certain extent more around that time, year 9, so I started being put into the top set… but then I worked harder and got there and realised I could do it quite easily.

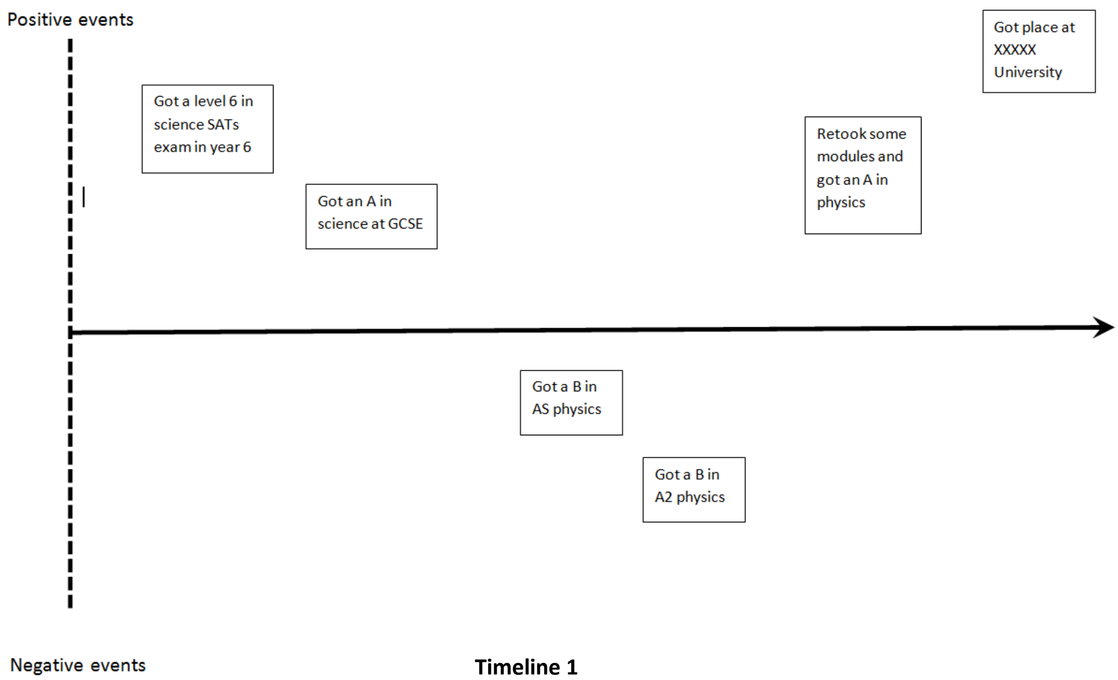
*A1OBM: When I was in year 8, I'd been set in not the top maths classes, she [*his mother*] did the pushy parent bit and made sure I was put into the top maths class...I was really shy, and didn't see myself as being someone who was particularly good at maths, whereas she did.*

This was in contrast to students at Einstein, where one of the undergraduates freely acknowledged ability in mathematics:

E1NFM: An important one is my ability to understand things mathematically, in the sense that I can look at physical problems mathematically, and I can look at some maths, and make a kind of analogy between the two of them.

This difference in recognising ability in mathematics may just be an anomaly of the sample; however, the self-recognition arrived during secondary education (in Key Stage 3). Cosser and Du Toit (2002) describe how higher education aspirations begin early in high school, when people start to look at occupational options. Their realisation of mathematical ability may have been influential in opening up the options for more mathematical subjects, including physics, for further study. The timeline below summarises the educational journey and achievements of one of the individuals. It is sparsely populated compared to some of the others; however, it is evident that this person reflects on the significance of their educational experience as a precursor to choosing physics as a degree.

Events that shaped your choice of degree



Timeline 1

The GCSE choices seem to have been made quite superficially, with A 'level options chosen without too much thought about the trajectory of their lives. Some students consider physics as an important subject for post-compulsory education (Stables, 1996), but Taylor (2015) found that students were more likely to choose physics if they perceived social pressure to do so from significant others. This is reflected by the research examining the wide range of influencing A' level choice: prior attainment and ability (Bell *et al* , 2007), perceptions and enjoyment; (Blenkinsop *et al*, 2006; Bell *et al*, 2005; Garrett, 1985), as well as career aspirations (Springate *et al*, 2008). This may be a stage in the developmental process where students lack the independence to assess their future trajectories with anything more than what the experiences of their life have already shown them. In this respect, we can see that the surprise at finding out that one is good at maths, along with the interests that have formed from external influences such as the media and familial encouragement, hold more sway with the forming early interests than the education system.

4.13 The influence of teachers

In May 2013, the Wellcome Trust published a report on public views on science and science education (Clemence, et al., 2013). The report highlighted that young people rated their school science experience highly, with 58% encouraged by a good teacher. This also mirrors the results of the Public Attitudes to Science study (Department for Business, Innovation & Skills, 2011), which indicated that science teachers were influential in shaping people's outlook on science. The graph (Figure 22) on the following page shows the results from the Wellcome Trust report on the significance of school education:

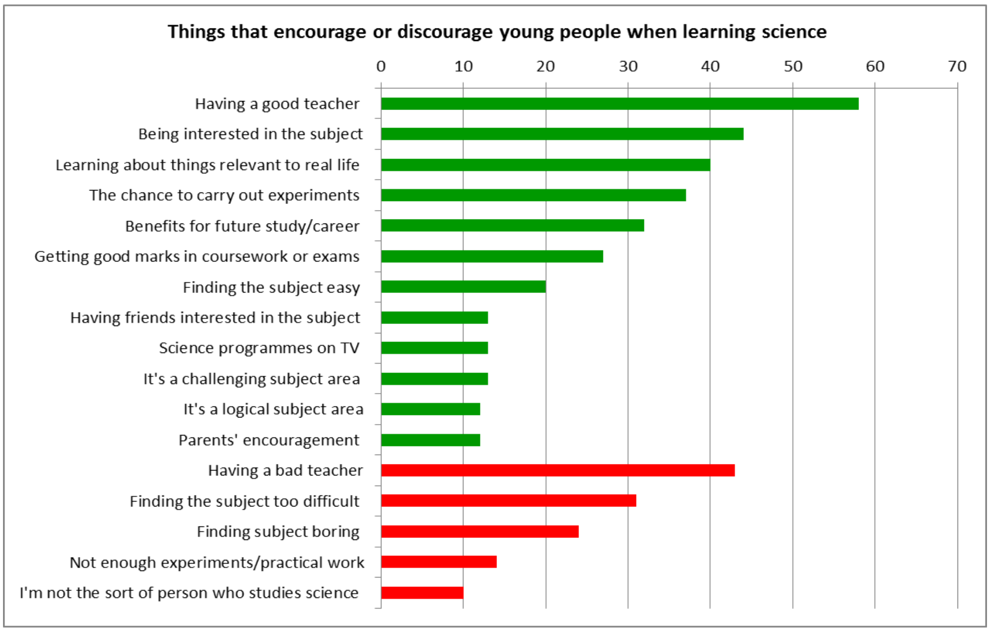


Figure 22: Things that encourage or discourage young people when learning science (n=480) (Clemence, et al., 2013)

There was some indication that A' level courses had more influence on the choice of degree than GCSEs. This may be due to the increasing experience and increasing understanding about what they were good at and what they enjoyed. There were indications that A' levels were perceived as a struggle for teachers, as all the respondents made some comment about teachers pushing for high grades whilst under pressure due to lack of teaching time:

A1AMF: I think the teachers wanted us to get the best grades possible in the exams, and we'd spend a lot of time just doing exam work.

*A2CCF: but she [*the teacher*] liked to keep everything on syllabus because there wasn't a lot of time.*

However, a point that was made by all the respondents was the influence of the A' level physics teachers on the choice of degree. There was no mention of whether these teachers were themselves physics graduates, although data presented by Kind (2013) indicates that "recruiting highly qualified, academic graduates is not an automatic precursor to ensure high-quality teachers" (p. 1315). For the purposes of this study, the respondents' reflection on their physics A' level teacher is considered an important in the field of influences leading to their decision to take a physics degree. This is confirmed by research (i.e. Archer *et al*, 2012; Brickhouse *et al*, 2000) that the initial interest in a subject may be sparked by family and the media, but as the person engages with the subject, it becomes those with specialist knowledge, the educators, bear more influence.

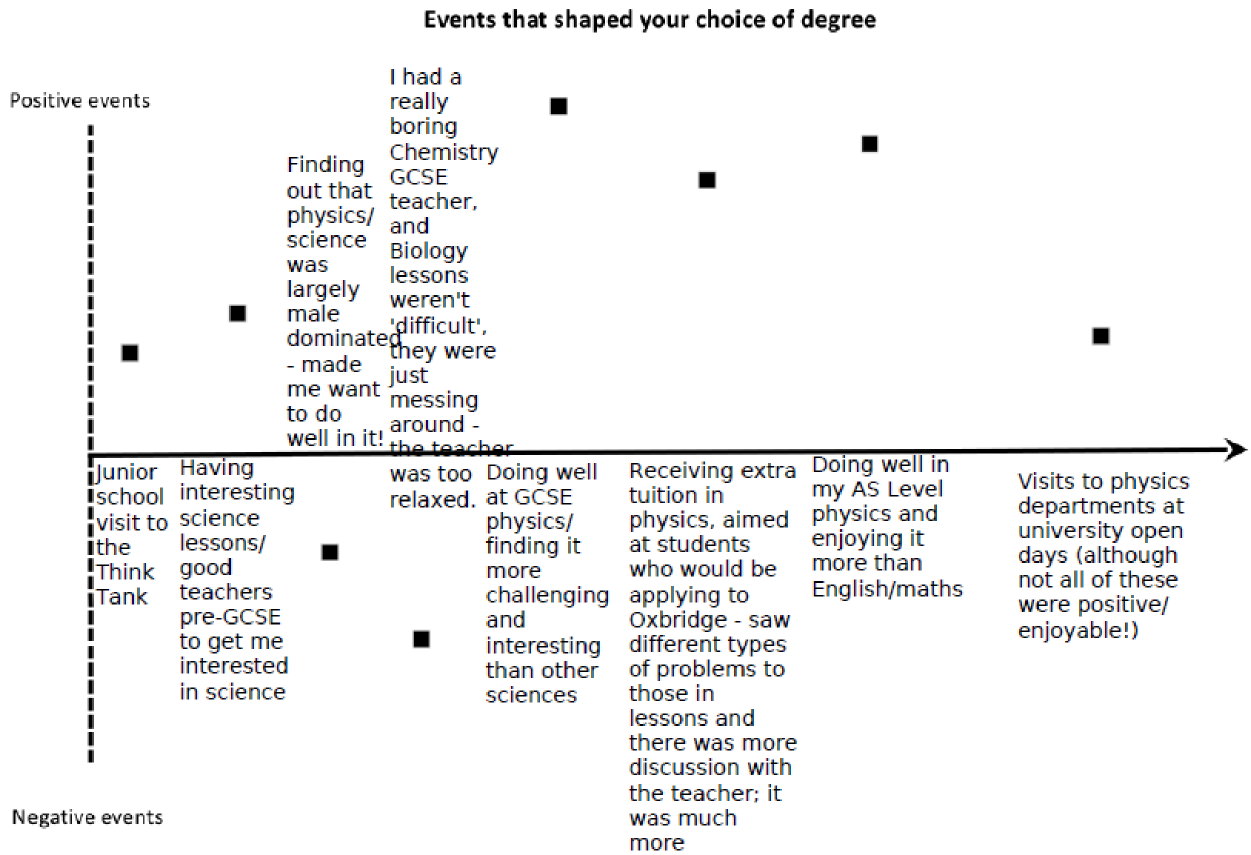
A1ASF: My physics teacher was quite passionate about physics and made the lessons quite interesting.

A1OBM: And I think that goes back to my A' level teacher being good at teaching physics and making us aware it was about assumptions and about building models.

A1PTM: And one of the teachers actually knew a bit of particle physics… and that got me really interested in particle physics.

A2CCF: He was really encouraging, got quite excited about cosmology, all the particles and the universe stuff.

It was noted that A2CC included her A' level teachers as significant influences. This is illustrated on her timeline on the following page (although her biology and chemistry teachers did not fare so well). Interestingly, the reasons for choosing physics were in some respects decided by her perception of the gender imbalance:



Timeline 2[52]

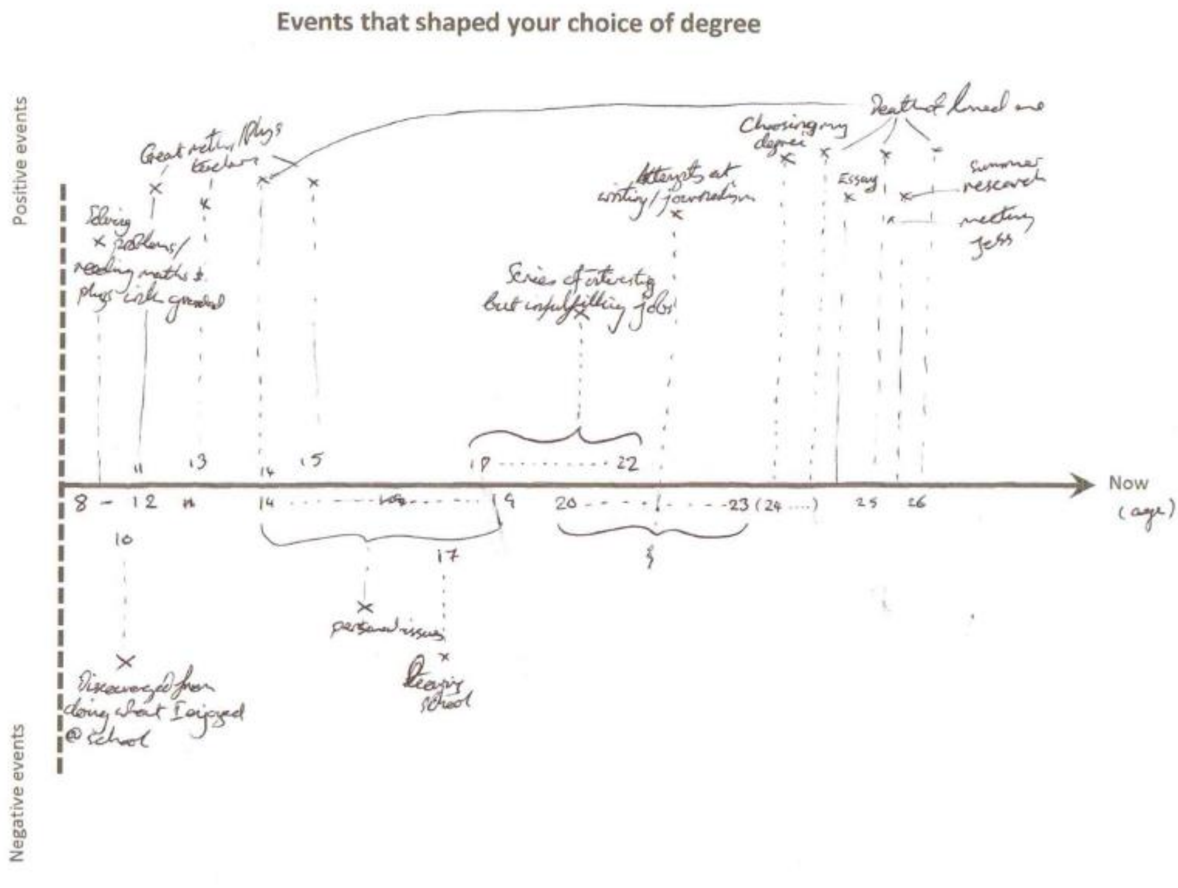
This trend was continued by all the other respondents, who signified that their physics teacher was a major influence on their decision to take a physics degree:

E1BCM: ... probably would be having a very, very good teacher at 6th form. A passionate teacher, a bit eccentric, who really cared about his subject.

E1NFM: And I did have a few good physics teachers as well... There was one particularly charismatic and pedagogical teacher I had.

[52] A note for this timeline: the events described refer to the dot above or below the line – the description is located in the opposite side of the line to the dot (so negative events are described above and positive events below).

This is also reflected in a further timeline where the individual highlights having a great physics teacher at an early age as a significant experience on their timeline:



Timeline 3

E2CPM: The most memorable physics teacher I had was in 6th form,... he was one of those quite laid back, cool type teachers, and incredibly knowledgeable about the subject as well, I mean he was very, very good.

E2NSM: ... having an interesting physics teacher.

Responses by the interviewees imply that their A’ level teachers were more influential to their choices made for post-A’ level education. In this regard, nine of the interviewees cited their physics teachers as having the most influence on their increasing interest in the subject. The formation of this interest may increase the desire for learning the subject, and thus the beginnings of a procedural identity are formed, within the supportive structure of education. Similarly, just as the trajectory towards a degree in physics is forming, there is some evidence that the other subjects chosen at A' level start to falter. There was much discussion by the respondents about the choice of chemistry A' level, during the analysis this emerged as within the major theme of laboratory work. Interestingly, all the respondents from Appleton completed chemistry A' level, whereas some of those from Einstein did not. These are a few key quotes that indicate their general feeling about chemistry A' level:

A1AMF: … *you did very little lab work at A' level. I think the teachers wanted us to get the best grades possible in the exams, and we'd spend a lot of time just doing exam work...*

A1ASF: *My chemistry teacher… just lectured the class, and we did practicals… and it was so dull.*

A1PTM: *And that pushed me away from experimental science towards physics, which has a bit less practical elements than chemistry generally.*

A2CCF: *then I enjoyed it* [chemistry] *anyway in class, not so much the practical side though, which was really boring.*

A2TGM*: I got to the point where I hated chemistry, with a passion… with lab work that I don't really enjoy, that made it harder for me.*

E1NFM: *I really like working in labs, but I break stuff quite a bit and I'm not very good at it.*

A report by SCORE (2008) noted that teachers struggled with the time and resources for practical science, with the report highlighting that practical work in science was decreasing. Their research indicated that 80% of teachers spent more than 40% of KS3 lesson time doing practical work, this fell and, with only 56% teachers at KS4 and 45% at KS5 spending more than 40% of time on practical work. It has long been recognised that it is A' level assessment and curriculum targets that influence the choices of practical work (Donnelly *et al*, 1996; Abrahams & Saglam, 2010). As Nott and Wellington argue:

> The skills and processes of investigations are not taught, but experienced, and the conduct of investigations is about summative marks rather than formative assessment to become a competent scientist. In that both pupils and teachers see them as more about getting marks than learning some science, the assessment tail is definitely wagging the science dog. (1999, p. 17)

Gatsby (2012) also found a decline in practical skills and that one factor was the "limited exposure to practical work at school" (Grant, 2011, p. 2). Despite the seeming disengagement with chemistry and its associated laboratory work, all the students continued on to a physics degree. An interesting continuation of this research would be to examine the significance of school practical work in chemistry or engineering degree level students.

The significance of laboratory work became a recurrent theme running through the undergraduate and graduate interviews, emerging through questioning on significant events and memories of their science education. There is a more detailed discussion of the significance of laboratory work continued on page 105, when I examine the events occurring during the physics degree.

In the next section, I will explore the structure and content of the physics degree courses, through analysis of prospectuses and interviews with the teaching staff at both institutions.

4.2 The significance of a physics degree

4.21 Engaging with higher education

Eidimtas and Juceviciene (2014) reviewed the literature on factors influencing enrolment in higher education. They present a summary of sub-factors: educational, information, economic and others (geographical location, ratings, personal skills and demography), which all influence enrolment into higher education. The authors discuss these factors in the context of decision-making for all types of degrees, and not just STEM or physics degrees; however, the respondents' included many of these factors in their decision to take physics degree. One important factor for their choice was through the information factors (Eidimtas & Juceviciene, 2014): the institutional prospectuses, open days and websites[53]. Carnvale (2005) identified that university websites are a primary means by which prospective students learn about higher education institutions, and are considered essential to institutional marketing practices. In this section, I will examine the prospectuses from the institutions to explore how these may have influenced initial expectations about the degree course.

The prospectuses highlighted key scientific discoveries in their departments, including Nobel Prize winners and leading research areas. Thorlindsson and Vilhjalmsson (2003) describe how society puts much trust in prestigious knowledge, namely the scientific knowledge produced by recognised scientists. There was some suggestion within the prospectuses that the institutions were reinforcing their validity as distinguished places to study: by highlighting in their course outlines the achievements that they have made in the field of physics. Rip (1997) observes that the authority of science is legitimised by the rigorous testing of research by other scientists, thus in these cases, it can be argued that institutional authority is being legitimised by the Nobel Prize winners within each department. Both institutional prospectuses indicated how research from their physics department was crucial to the

[53] Whilst examining the websites and prospectuses of the institutions, I was reminded of my examination of the epistemological theories of scientific knowledge that I had discussed in my critical analytic study. It seems that under the mantle of the epistemology of science, knowledge was once considered paramount in the concept of science. In contrast with these philosophical traditions, newer studies indicate that science is now about practice and method (i.e. Pickering, 1992). Callon (1986) and Latour (1987) also describe how scientists construct authority in society by positioning themselves with a crucial role.

future of society, whether it be 'leading research into the effects of climate change' or 'medical applications of physics'[54].

4.22 Social expectations of a science graduate

The concept of objective methodology also seems to reinforce social expectations of what science is, and to some extent influences student expectations about physics prior to enrolling on a degree course. The preconceptions of scientific objectivity and the ideas of science knowledge taught in schools may lay these referential foundations for student expectations. It is evident that the Institute of Physics also recognises the significance of scientific practice and method, emphasising that:

> All graduates of an accredited degree programme should have some appreciation of physics as an experimental science. They should have an understanding of the elements of experiment and observation and should therefore be able to
>
> - Plan an experimental investigation;
> - Use apparatus to acquire experimental data;
> - Analyse data using appropriate techniques;
> - Determine and interpret the measurement uncertainties (both systematic and random) in a measurement or observation;
> - Report the results of an investigation and understand how regulatory issues such as health and safety influence scientific experimentation and observation.
>
> (Institute of Physics, 2011, p. 3)

Social constructivism has developed arguments countering the idea that science is purely an objective experience, indicating that perceptions and observations differ because of personal experiences of culture, history and language.

> [S]cience is shaped by the personal beliefs, education and political attitudes of its practitioners. The institutions of science, and the deployment of its practical results,

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[54] For the purposes of anonymity, the specifics are not quoted verbatim.

> reflect, in part, the history, power structure and political climate of the supportive community (Dixon, 1973, p. 71).

This social construction of science knowledge raises questions about what students will learn, and participate in, within their education. A degree education will reflect the interests of the training group; for example, an advertisement for the Masters course in Physics from Kings College London highlights that students will be taught by lecturers who are conducting research at an international level (Kings College London, 2012). This puts the education system in a difficult position; in order to practice science, students are required to collaborate subjectively, whilst learning that it is objectively constructed knowledge. There is some evidence for this conflict here, as many students may find that the experimental side of physics is actually the more social and subjective area of their study. This will be discussed further on page 110.

4.23 The influence from industry

Both prospectuses indicate that their physics departments have links with industry and acknowledge that this relationship is beneficial in terms of post-graduation prospects. The emphasis on industrial, economic or military applications that scientific methods can augment (Salomon, 1985) indicate that in contemporary society, science has become a measurable commodity. Interestingly, during one of my visits, I was aware of how key student areas included much advertising from the financial sector for physics graduates. This indicated to me that the financial world had recognised the students attending that department as something of a captured audience, investing heavily in sponsorship and funding of student events. This can be interpreted as some evidence that science, both in education and research, is no longer determined by scientists, but by political and private institutions, and policy makers who remain receptive to economic opportunity, engaged in encouraging physics graduates out of the domain of physics and into different, possibly more financially lucrative, domains. It seems that Habermas (1984) may be right in believing that science has become a tool in the heart of politics and economics, a product that can be bought and sold because the knowledge that it uses to manipulate nature can in turn be manipulated. Thus, the search for truth is no longer the objective of modern science; instead, its power lies in the search for practical results and economic progress.

Many variations of physics course are available at universities; courses that deliver 'general' physics or combine physics with another subject. Both staff interviewed stated that the more mathematical course was theoretical physics. For the purposes of this study, I limited myself to studying the single Honours Degree in General Physics, as I saw this as a better reflection of the physics taught in schools to A' level; thus students on more applied courses (of which there are innumerable variations) are not included. There is much potential for examining these more specialist courses and the impact that they have on occupational destination, but for the purposes of my study, I focused only on the broader course[55]. The institutions both highlighted that their degree would increase graduate employability by developing transferable skills such as problem-solving, reasoning, practical skills, and programming.

The single Honours Degree is a three-year course, but includes the option for third-year students to continue a further year to gain a Masters level qualification. In the two institutions studied, both had Institute of Physics accreditation[56]. Most physics courses include this, as the IoP rigorously checks that core physics principles are taught. There were many further similarities for entry onto the courses, with both specified the need for A' level mathematical skills, but both courses also began with an

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[55] This reflects my background as a scientist, as throughout this research I had an internal conflict between my desire to carry out a valid scientific method (with minimal variables) and my status as a qualitative researcher.

[56] This accreditation is the method by which the Institute of Physics monitors the content and standard of physics degree courses. The accredited degree courses must include, as set out by the Institute of Physics:

- Degree programmes should provide a positive experience of physics and should encourage the student to foster and maintain an intellectual curiosity in the discipline.
- All degree programmes including joint and combined honours must impart a secure knowledge of the fundamental elements of physics as expressed by the Core of Physics. However, the Institute expects that programmes will be taught to a considerably richer curriculum than the Core of Physics and will include advanced material reflecting the specialist interests of the department.
- All programmes should enable students to acquire the skills listed in the Graduate Skills Base. These skills consist of both physics skills and transferable skills.
- BSc degree programmes must incorporate either project work or a dissertation.

(Institute of Physics, 2011, p. 2)

introduction to the mathematics necessary for continuing physics. Individual courses as described by prospectuses did not vary much, with similarities in structure including lectures, practical sessions and tutorials.

4.24 The perspective from degree teaching staff

I interviewed the teaching staff at each institution, to gather more insight into how they viewed the aims of the degree. In both cases, the staff initially gave me department policy, but then spread into personal viewpoints. Thus, for the purposes of anonymity, the lecturers have been identified with suffixes of TS (Teaching Staff); Appleton is coded AX and Einstein EX. It was during these interviews that differences between the courses started to emerge. These differences also surfaced in the eventual reflections by the students, which will be discussed in later sections.

Initially, it was evident that the staff viewed the IoP material in different ways: staff at Appleton noted that:

AXTS: *Some of those are imposed from higher up, so for Institute of Physics Accreditation, they say you must know this, that and the other, but none of those impositions are a hindrance in any way because if I was to design my own first years mechanics course without any of these requirements it would definitely incorporate everything I'm told to do.*

However, the accredited material was seen as time consuming by staff at Einstein in terms of fitting into the timetabling:

EXTS: *We have the Institute of Physics accreditation, which means that for the first two years it actually is very tightly constrained; particularly with the restructuring of the academic year, it's hard to fit everything into those two years.*

At Appleton, there was time dedicated to core physics in the first two years, with options then chosen in the third year:

AXTS: *The way* [Appleton]*does it, we absolutely fit everything in the core in the first two years. Except we can't quite so there's a little bit of an overspill to the first term of the third year ..., so for the first two years all 250 students are in the same lecture theatre together, experiencing the same lectures, doing the same labs, doing the same computing. And then, in the third year they are picking optional courses from a huge range and doing optional experiments and optional projects.*

Einstein described a similar structure of the course:

EXTS: [the first two years]… *Everybody does everything: theorists do more maths, and people who are desperately keen on astronomy do more … The options really come in the third year; in fact even in the third year there are some that are core-like, such as Nuclear Particle Physics, and then Condensed State Physics.*

The reasons given for these timings were logical, as described by the lecturer at Einstein:

EXTS: *as time goes on and they get a better flavour of the core courses in years one and two,… then you get a feel of it and can then make the choices appropriately later on.*

From the staff point of view, expectations at the beginning were considered to be somewhat rose-tinted (see a later discussion on student expectations):

AXTS: *There's some who are really keen on astrophysics and who don't want the 'physics-with' mix and there are others* [courses]*but it's just purely for bringing students in. For the first couple of years it doesn't make any difference whatsoever and then when they're here they can specialise more if they want.*

EXTS: *They're incredibly keen on physics; nearly all the ones that we get through the door are really keen on the subject, as you'd hope for... I think it's just something of an expectation they've generated from reading a Brief History of Time and watching Brian Cox on the TV. You know, physics at university is going to be all this cosmology stuff – which it can be, but they don't get to grips with it until the third year.*

The prospectuses of both Appleton and Einstein specify core modules including Mathematical Methods, and classical topics such as Mechanics, Electromagnetism, Optics, Thermodynamics, and Relativity. Modern physics such as Quantum Physics, Atomic Physics and Computing are also part of the compulsory teaching modules. It is evident from the outlines of the courses from both these institutions, and several other institutional prospectuses that there are very few differences in undergraduate core topics. The overview indicates that all physics graduates need a solid base in the foundational physics knowledge, similar to secondary education, where the 'history' of science knowledge is imparted to the students. As the Institute of Physics prescribes:

> The content of the 'Core of Physics' is intended to represent the crucial physics knowledge and techniques that every graduate is expected to have understood by the end of their course. (Institute of Physics, 2011, p. 2)

4.25 Training for potential careers

A further influence on institutional choice is with the career potential that each institution offers. Occupational potential and professional skills training were viewed as important in terms of how the teaching staff viewed the aims of their courses, although the lecturer from Einstein emphasised the importance of career guidance in far more depth than Appleton did.

AXTS: *They always have professional skills. And I think that that's a fairly standard thing so in the first year there's things like how to do group or individual presentations, that kind of malarkey, then it moves on to CV writing and then there's a bit of careers* *guidance involved with that, and then they have regular meetings with personal tutors about that.*

EXTS: *Careers; we used to focus on the academic side if you like and take most interest in those students who go on to PhDs and so on, but now there's a clear recognition that that is not the norm. Something like 40% of our students go on to further study. But 60% don't, and now we actually have a careers module integrated into the curriculum… this careers module that we've got teaches skills - interview skills, CV writing, how to write a cover letter – it turns out that some of these students have never written a letter before – so there you go, there's an example of a perceived need that goes beyond the research shaping of the curricula*.

During part of both interviews, the lecturers discussed the issue of physics graduates working in non-physics related occupations. There was an interesting difference between how each lecturer viewed physics graduates entering the non-physics sectors, such as finance:

AXTS: *Funnily enough, I try to do whatever I can to steer them away from finance without saying it. I've got a very rewarding job, but I don't find it that rewarding when I see an excellent student who I've worked with for years, going on to a lucrative job in finance. They'll be wealthy if they work in finance, but they won't be wealthy and they might find it difficult to get work, if they do a PhD.*

There was evidence that both the lecturers had different attitude towards these external domains. The Appleton lecturer interviewed implied that he actively discourages students away from finance domains, although this was not an official Department policy. There may be possible ethical considerations to this discouragement; however, he also acknowledged that no potential student had ever been rejected based on their desire to enter financial markets. He also acknowledged that the financial corporations had a large presence during undergraduate career fairs;

attracting undergraduates with potential career prospects and those who wished to follow business roles. A recent article in The Economist refers to the current state of university education in America:

> Higher education needs to do more to prove its worth. At present, although it is clear that individuals, on average, benefit from a college education, it is not clear whether this is because their degree certificate signals to employers that they were clever enough to go to university to because their studies added to their human capital. (Duncan, 2015, p. 19)

There was evidence of a financial and corporate presence when I visited the Department, with newsletters and posters displayed in prominent positions. The newsletter that I read (whilst waiting for my interviewee) advertised financial occupations for physics graduates, as O'Donnell (2010) states, these corporations require physics graduates to do predictive analytics and risk modelling.

At Einstein, the staff interviewed that explained that as a physics department, they actively encourage graduates to consider the possibilities of a future occupation in business by incorporating a finance and physics course as an option:

EXTS: *There's a close link between physics and the kind of modelling that people do in finance. We've just introduced a [*finance*] module*[57]*, even though we don't have any financial people, there are still physics-type methods of solving equations and modelling and so on that are applicable to that.*

This reflects the ideas of Nespor (1994), who describes how the identities of physics students are separated by the limited social world of academia, compared to business, where the social space is expansive. It seemed that Einstein was trying to expand the social space for their students beyond academia.

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[57] Finance was also offered at Appleton as an optional course but not taught in the physics department.

Baskaran and Boden (1994) have also argued that science has become commodified as the activity of science has moved from a relatively independent socio-economic space (the traditional model) to the private and marketised public sector. There is further evidence in the literature that scientific research is shifting from academic needs for knowledge towards the political and economic arena. The interview transcripts from the teaching staff support this notion that economic and political pressures are transforming the physics arena away from advancements in knowledge. Salomon describes the changes as a science that no longer is "considered as a system of knowledge outside the economic circuit" (1985, p. 79). As Ziman argues

> The transition from academic to post-academic science is signalled by the appearance of words such as management, contract, regulation, accountability, training, employment, etc. which previously had no place in scientific life. This vocabulary did not originate inside science, but was imported from the more 'modern' culture … characterised by Weber as essentially 'bureaucratic'. (Ziman, 2000, p. 82)

In this brief analysis of the two institutions, it is evident that both Appleton and Einstein were committed to completing the Institute of Physics accredited material within the first two years. In terms of overall structure and content of the courses, there was little difference. It is evident that the information (marketing) factors would have contributed to the early field of influences; in encouraging the individuals to apply to each institution and in the formation of expectations of what each course would entail. Thus, the significance of a physics degree is subject to a variety of influences; the images of a high status subject in the prospectuses, the necessities of traditional taught concepts, the expectations from society and the external agencies such as industry and the media. In the next section, I examine further themes that emerged during the interviews in relation to the educational events experienced on each of these courses.

4.3 Theme 2: Educational experiences influencing physics identity

4.31 Laboratory work

During the analysis of the student and graduate interview data, laboratory work emerged as a major theme. The discussion about laboratory work was evident throughout every stage of the educational experience, from school to degree level. In terms of school education, the respondents[58] were all significantly influenced by their A' level teachers to continue physics to degree level; this was previously discussed on page 92 . Grant (2011) concluded that it was the view of university staff that new undergraduates were lacking both practical skills and the confidence to carry out practical work within a laboratory. It was evident that teaching staff at both institutions were aware of issues with laboratory work, as both voluntarily discussed problems with it during their interviews:

AXTS: *And I think that some with the unrealistic expectations, don't like certain aspects of school physics, like laboratory stuff and, despite the fact you tell them - Look, you're going to be doing six hours of laboratory a week, for the next three years and that's compulsory - they still sort of think, "we can get that out of the way as soon as we can and move on with the interesting stuff"… So I think a lot of it is to do with being exposed to it, and certainly a lot of them for science subjects, I'll say did you like lab at school and they'll say, chemistry yes, but physics no, seems to be quite a common one.*

EXTS: *People say 'I want to do theory because I don't like lab'. If we hear that we would absolutely discourage them...The labs are critically important and it's interesting trying to develop enthusiasm for the labs because a lot of students come in who have never really played with lab equipment in schools and are nervous about it and uneasy and don't necessarily enjoy it, particularly at foundation level.*

[58] Both undergraduate and graduate.

The reflections on school laboratory work had included both positive and negative experiences[59]. There were positive reflections of laboratory work during the degree course, and acknowledgement that it was a necessary part of a physics degree:

A2PT: … so even though I've never really enjoyed labs I appreciate they're important.

A1OBM: *They were all good, because they* [the labs] *were very clear confirmations of the stuff you were learning about at the time.*

E1NFM: *Because not having the labs to look at the physics you're doing … you just become a mathematician, looking at physics and it's not the same thing to me. So labs are wonderful and I wish I was better at them.*

E2CPM: *But the actual labs we did I really enjoyed. I love the practical science, actually getting to do experiments. It was something I'd missed from studying GCSE and A' levels, and was very happy to get back into it at uni.*

E2NSM: *in labs you … get results, look at them, and try and look at why your results are different and … there's plenty of scope to mess around with and I'm a practical person. I like to get my hands dirty.*

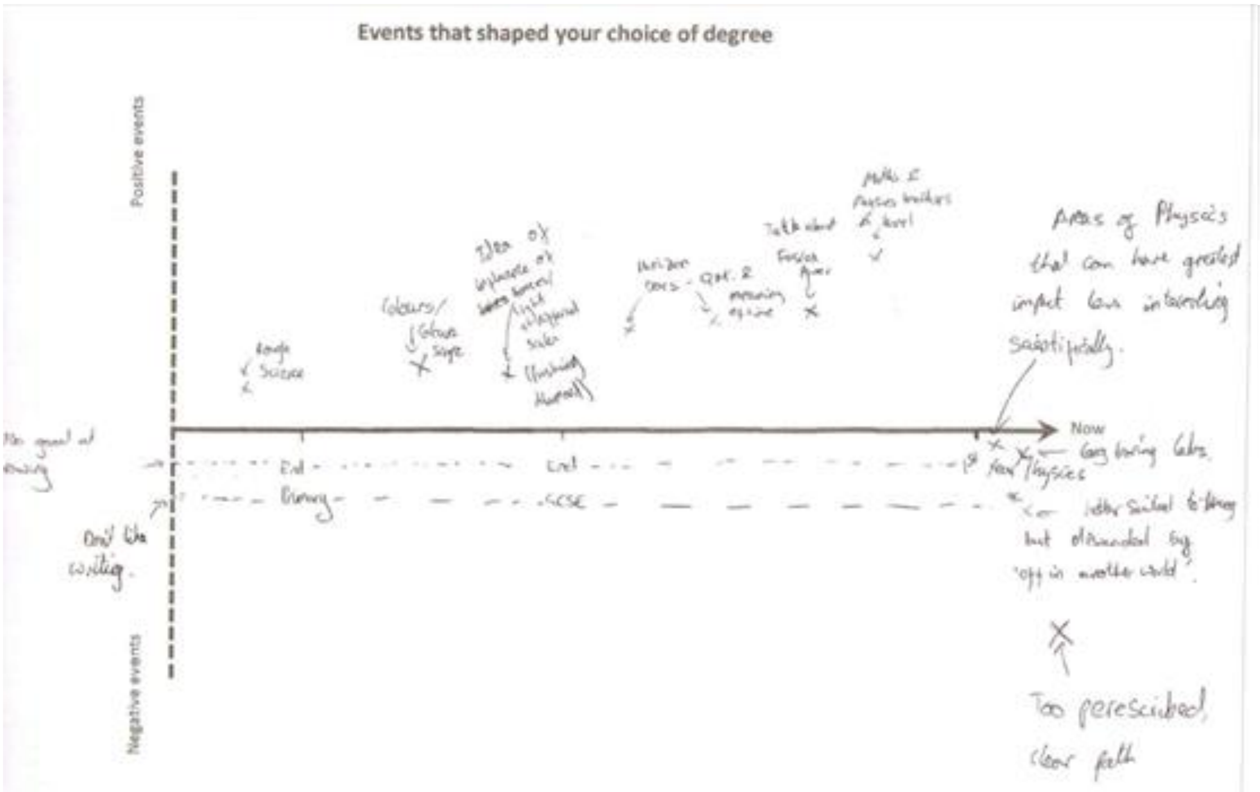
E2NSM: *I'll say I learnt a whole lot of really good practical skills…it turns out that there are useful things you can do as a physicist.*

This is not surprising, as physicists and educational researchers consider experimental

[59] As discussed in previous section - Theme 1 (page 86). Also mentioned in the timelines (Appendix E) for individual details on events in the A' level lab.

work as a fundamental part of physics teaching and learning, and many authors argue that physics is more effectively understood using practical work (Hegarty, 1990; Newble & Cannon, 1995; Trumper, 2003). I am taking laboratory work as one of the major themes as all the respondents reflected on significant experiences of laboratory work during their education.

It seems unlikely that any single physics, or indeed, degree course, can fully address all the aims[60] of practical work, but there are some implications for how school experimental work is viewed. The students and graduates all included significant reflections on their experience of laboratory work during their degree experience, and raised some interesting points. In the diagram below, it can be seen that A1OBM described 'long boring labs' as a negative event on his timeline:



Timeline 4

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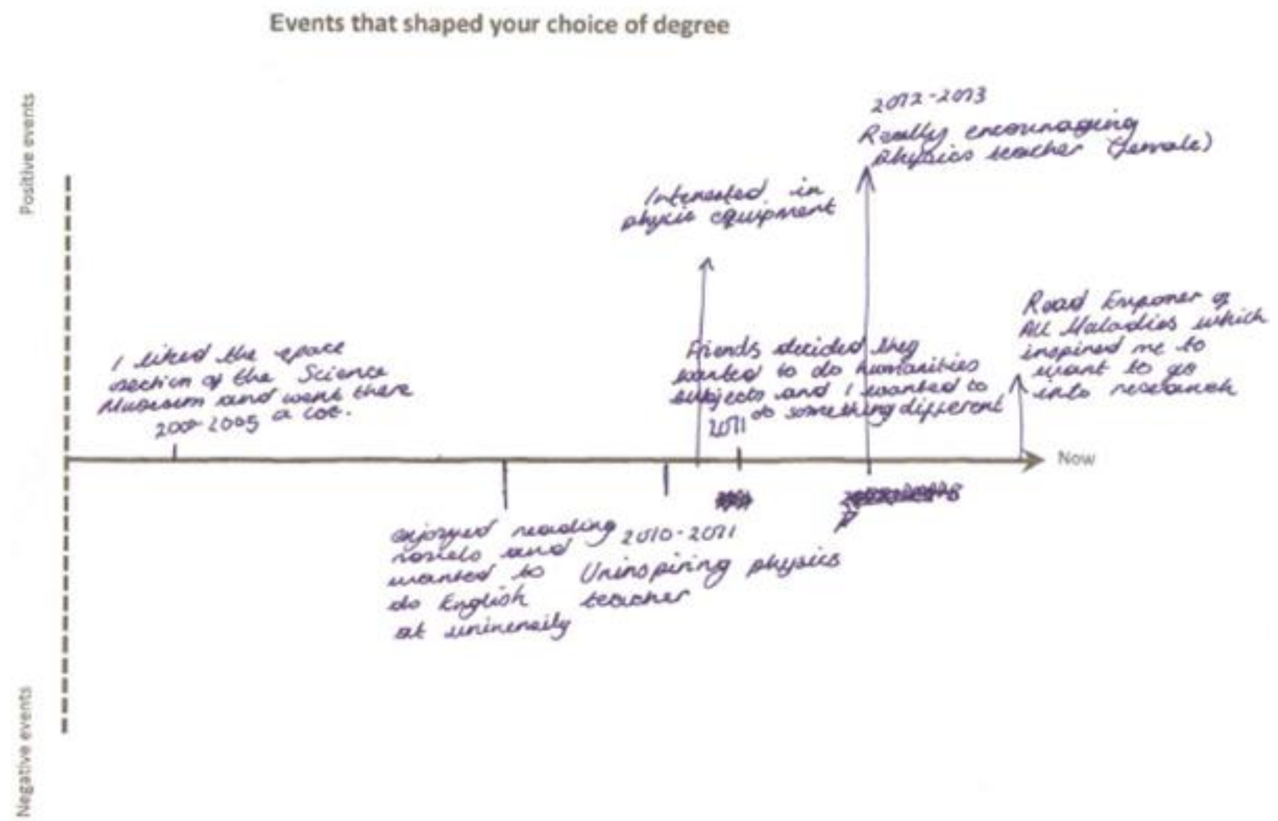
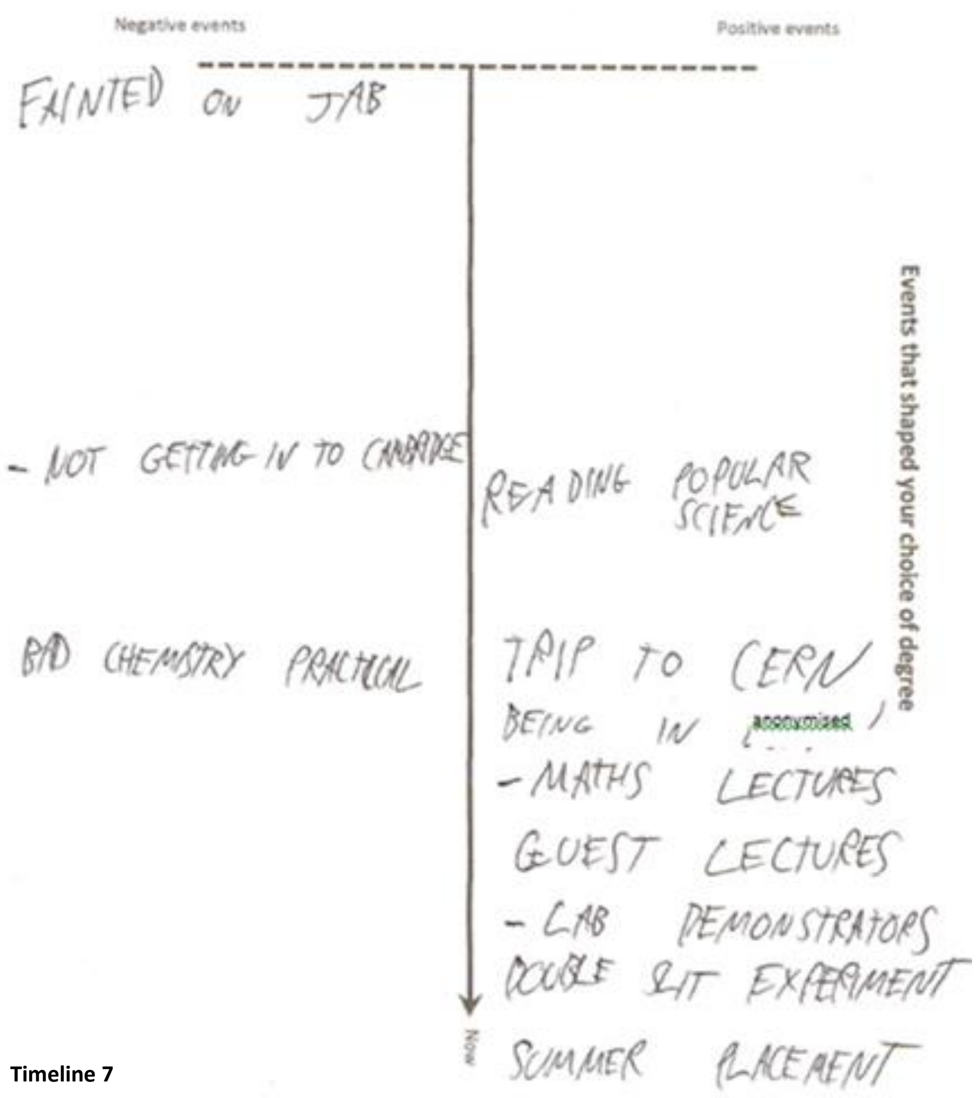
[60] Brown and Atkins ((1988, p. 91)) state that the main purposes of practical work in the laboratory are to:
• Teach manual and observational skills relevant to the subject;
• Improve understanding of methods of scientific enquiry;
• Develop problem-solving skills, and
• Nurture professional attitudes

Conversely, another undergraduate (the first year A1AMF) stated interesting physics equipment as a positive influence for choosing physics:



Timeline 6

This was also evident in another timeline, that of A1PTM, who gave examples of experiments as positive events during his degree:



Timeline 7

Boud *et al* (1986) describe how practical work can be classified into three categories, all which reflect educational experiences of the interviewees. Firstly, experiments are prescribed by teachers and marking criteria, similar to those experienced at A' level. Experimental investigations are the second category, where students have opportunity to conduct experiments more independently; the students and graduates described this as part of their early degree-level laboratory work. Finally, the third category is the research project, where the students have access to 'real life' research experience. In some of the examples below, the students talk about their final projects as being far more meaningful to them than the initial core laboratory work:

A1ASF: *But when you spend 6 months on your final project it's a lot more depth and... you feel as a student more doing something useful in physics. It was less tied. You were given a problem and sent on your way and told to figure it out yourself really. It was a lot more difficult than lab stuff but a lot more enjoyable, a lot more meaningful.*

A2TGM: *I guess my final year project ... is what I enjoyed most about my degree. It was a big, discreet piece of work and it was yours and you owned it. When you did discover something new that people didn't know before, that was most rewarding, although in the scheme of things it was quite small, but I found that quite fun...*

It was also noted by one of the respondents that the physics learnt in laboratory sessions during an undergraduate degree differed from that of 'real physics':

A1OBM: *There was never much setting up of equipment in undergraduate labs ... what they try to do I think, is to build on what you might have learnt in your studies and try to develop the idea of trying to analyse data, but what they don't do, which is done a lot in real physics, is make much.*

This is supported by work by Wang and Coll (2005), who also found that students seem to feel they can learn physics better when they conduct the experiment more independently as scientists do (p. 664). Nevertheless, for many of the students, the positive aspects were not related to the learning experience, but to either the novelty of the situation, or the social aspects of working with a partner.

A1AMF: *We get on quite well, me and my partner – you have the same partner for the* *whole year. So you end up building quite a good friendship, learning to work with each other, which was nice.*

A1OBM: *We were recording our own spectra on film and then had to develop the film. That was fun but it might have been for the wrong reasons ... Just fun to have your hands on the film and then develop the photograph... That was cool.*

A2CCF: *I remember I took it [experiment results] back to the TA and ... he was so excited, because it wasn't fuzzy at all... that was a good laugh!*

E2CPM: *So the labs were always a good laugh. There were numerous high jinks as well, like people playing small pranks on each other and winding each other up...*

E2NSM: *I did enjoy the labs very much. I enjoyed them because I got to play around...*

What became apparent during all the interviews was the lack of productivity that many of the individuals felt occurred during laboratory time. Following the initial enthusiasm on their reflections of practical work (mainly during a comparison with school laboratory work work), all the interviewees became much more negative about this side of the degree experience. The data from the respondents from both Appleton and Einstein has shown me that the laboratory work may be one of the major things where the physics students struggle the most.

A1AMF: *They were OK to begin with, but then you have to swap out lenses, you've got about 15 different lenses to use and you'd measure the interference pattern of each one. Gets a bit tedious!*

A1OBM: *I found them quite tough, I think. They're really long, they take a lot of time, and in first year it was confusing because there were a whole load of things I'd never been taught very thoroughly before, or just having come across by having been put in lecture notes.*

A1PTM: *Interestingly even if you do a theoretical degree, you have to do labs in your first two years, which isn't something I particularly enjoy... Chemistry is very big on practicals. I'm glad I didn't do chemistry.*

A2TGM*: I don't deal very well with repetitive tasks and find it annoying having to do experiments.*

E1NFM: *I really like working in labs, but I break stuff quite a bit and I'm not very good at it....*

E2CPM*: I missed the first lab course you do in physics, which was data acquisition, and analysis, which from what I was told was horrifically boring so I didn't really miss out there...*

The evidence points to several key issues that is relevant to science education in schools. This is of interest to me, as much of school education revolves around learning the skills in laboratory work. Much focus has been directed towards education school pupils in the art of 'how science works', now 'working scientifically' (Department for Education, 2014). The importance of data collecting skills shows that many of the students were unprepared for the level of analysis and detail required in degree level physics. The second issue here is the use of equipment: required practical skills seemed to have been neglected during A' levels and consequently, not many of the physics students had much practice setting up equipment prior to entering the degree course. This was also noted by the staff interviewed and backed up by research by Grant (2011), who found that some university staff at Russell Group Universities had adapted their first year laboratory teaching to better prepare students, including simplifying first-year lab courses by providing more step-by-step instructions, removing complex experiments or allowing more time.

It is interesting how much the respondents had changed from their younger, pre-university thoughts of enjoying finding out how things worked, to individuals bored by the monotony of data acquisition. This is reflected in the work of Wang and Coll, where they comment that "It seems unlikely that simply recording seemingly endless data and inputting such data into some formula is going to encourage student interest in practical physics" (2005, p. 666).

Identity theory states that individuals in modern society have multiple role identities, which correspond to the different social roles they fill. They are differentiated based on social (e.g., a science student), group (e.g., racial identity, Tajfel & Turner, 1986) and personal (e.g., a nice person, Hazari *et al*, 2010). Numerous studies support the premise that persistence in STEM education requires mastering scientific skills as well as the social psychological process whereupon students see science as a relevant part of their identity (Carlone & Johnson, 2007; Hazari *et al*, 2010; Johnson *et al*, 2011; Egan *et al*, 2012; Merolla *et al*, 2012).

Research by Hurtado *et al* (2009) also found that undergraduate research experiences enhance student interest leading to improve their knowledge and understanding of science. Thus as the students progressed through the degree course towards their final projects, they had enough knowledge to complete their individual research projects 'like a scientist.' There is some variety here in terms of those who reflected on the practical and intellectual skills and those who reflected on their self-perception had matured. To some extent, this development of personality is reflected by their increasing maturity[61], but at the same time, it was evident during the

[61] This was described by Super (1957) in his work on vocational psychology whereby individuals acquire maturity, ability, skills, talent, and interests that enable future goals. Betz and Hackett (1981) have also examined the relationship between maturity and development of the self in their work on how a person perceives themselves when making a judgment or a plan related to a career decision.

interview process that the individuals were taking some time to reflect on how they viewed themselves before and after their degree. This, together with the process of completing the timelines, was an experience that allowed the respondents' time to describe the events that I understood to be significant from their perspective.

4.32 Laboratory reports

Another second issue deemed significant by all the respondents was that of the reports that were necessary following laboratory work. The lack of writing skills by science undergraduates has been discussed by Deiner, Newsome and Samaroo who describe how "many incoming first year chemistry students have not yet developed the necessary writing skills to compose a laboratory report" (2012, p. 1514). Similarly, a study by Chirwa (2007) identified that reports written by engineering undergraduates revealed inadequacies, apparent in both first year students and later years of study. This was reflected in my interviews with both under- and post-graduates, where it was evident some had difficulty with the level of analysis and depth required in scientific report writing.

A1AMF: D*oing proper labs and keeping a lab book was all new to me, and I think to a lot of other people as well.*

Chirwa (2007) argues that some students believe that report writing is not a valuable component of their field of study, however the process of report writing was considered to be a positive part of the learning journey by the females from Appleton:

A1AMF: *We have to keep a lab book of all our work; it has to be quite detailed, and I like recording the experimental process... The actual experiment always seemed secondary; the main purpose seemed to be for us to learn the etiquette of writing a lab report and keeping a lab book and things like that.*

A1ASF: *And writing your report, it was a reflective thing so you could figure out what you were writing, …, so it would inform your next lab cycle so you could see that you were definitely improving during the year...*

It was evident that all the males from Appleton institutions struggled with report writing, but this may relate back to how resilient the individuals were in terms of feedback received. Interestingly, the females (see above, A1ASF) also received poor feedback, but seemed to see beyond this to the larger picture of why it was necessary for reports to be written. There was more differences between genders than between the institutions. The male students[62] found report writing the second most frustrating part, after laboratory skills.

A1OBM: *And writing lab reports was ok in the first year, but it got really tough in third year.*

A1PTM: *My marks for labs aren't particularly bad, but they are not as good as other people. …you can just end up with lower marks because labs are assessed by coursework, not an exam.*

A2TGM: *It wasn't the actual lab I found boring, it was more the write-up of lab work I found quite laborious... Just writing up in tedium and method I thought was, well it wasn't as bad as A' level.*

The discussion about report writing was more positive from Einstein, but this may stem from the better feedback given to students at Einstein. It is worth noting that from the students at Einstein, only one is continuing with further studies in physics and

[62] See Table 1 Summary of interview sample on page 74

he made no comment about report writing during his interview (as he only completed four hours of lab work over the three year course of his degree[63]).

E1BCM: *It was a refreshing change, because physics is often so maths-based, but it's absolutely essential, given the style of writing in physics is very different to any prose I'd written earlier in my life.*

E2NSM: *I both enjoyed and didn't enjoy it. Writing reports was fun when I found it engaging and not fun when I found the experiment not engaging ... when I was engaged I would write very in-depth reports ... when I was not engaged ... I would just not do it.*

It is noticeable that within the interviews, all the respondents voluntarily discussed report writing, and I asked no direct questions about the writing of reports. In terms of critical incidents, these events may not seem momentous; however, the ability to write well is crucial for success in both undergraduate classes and any science-related occupation (Coil *et al,* 2010). In the study by Kardash (2000), writing skills were considered the least enhanced over a research skills training course; similarly, Seymour *et al* (2007) found that benefits of undergraduate research courses did not include improvements in formal writing skills. There may be some basis here for examining how school education can provide a foundation for these skills, not only for physics

[63] There is a clause within the Institute of Physics accreditation that indicates that there is an option for those not engaged by experimentation to follow a more theoretical course:

> … these required skills could be acquired through computer simulation, paper exercises with appropriate data, or case studies using real experimental data from a published source. (Institute of Physics, 2011, p. 3).

This may be a consequence of the more philosophical and theoretical stances of modern physics, where theory is provided for, not by experimentation, but by mathematical models.

report writing, but also in all areas of science and the humanities where extended prose using a specific language is required.

4.33 Assessment and feedback

In higher education, feedback is considered central to the development of effective learning, as assessment procedures are considered to play a key role in shaping learning behaviour, and it is argued that feedback accelerates that process (Sadler, 2010). Clark (2011) noted that assessment is instrumental for measuring, and feedback is an integral part of assessment (Angelo, 1995). A task that is assessed requires a judgement of the students' work, and the subsequent feedback allows the student to bridge the gap between the current and desired status (Sadler, 1989). It can be seen as a product, as a consequence of "information provided by an agent (e.g., teacher, peer, book, parent, self, experience) regarding aspects of one's performance or understanding" (Hattie & Timperley, 2007, p. 81). Feedback is seen as a critical part of this learning process, empowering students to become self-regulated learners (Carless, 2006). Within the school education system, feedback is considered a major aspect of pupil learning and progress (Beadle, 2010), and so, because of the emphasis placed on school feedback, student expectations of university feedback may be raised. Research has shown however, that university feedback is an area where expectations do not match experiences (Brinkworth *et al*, 2009; Crisp *et al*, 2009; Thalluri & King, 2009).

Carlone and Johnson (2007) describe how the shaping of a STEM identity occurs through self-verification along with external acknowledgment (i.e. feedback) and experience. Their model of science identity includes three elements of competence, performance, and recognition. Students with strong science identities can demonstrate competence, possess skills to perform scientific practices, and achieve both self-recognition, and from others, as a scientist (2007). This links to the respondents' desire for feedback on their submitted work: necessary to demonstrate competence and reinforcement of their self-recognition as a physicist. The interviews however suggested that most of respondents felt frustrated at the level and clarity of the feedback given:

A1AMF: E*ach lab report is* [marked] *by a different demonstrator so they each have their own style of marking. Quite a few of the marks go on general presentation of the lab report, so one of them will tell you "you should have put your graph in grids or you should plot errors…" So it's a bit confusing in that sense.*

A1PTM: *When I have received work back sometimes you don't get any comments on it but then if your mark is 70% maybe they just think it's good and you feel you shouldn't complain because 70% is a good mark. But naturally it begs the question, 70% as opposed to 75%, could you highlight the bits I didn't do that well?*

The above comments are made by both a female (A1AMF) and male respondent (A1PTM). Research on gender and feedback (Adams *et al*, 2000) suggests that males consider the primary role of assessment to provide a mark representative of their capabilities whilst females consider giving feedback on progress to be most important. This is also reflected by the feedback below (another female, A1ASF):

A1ASF: *We'd get our assessed problem sheet back with some basic marking on. The lab report feedback was better because they'd mark it then give you a cover sheet with comments on and then you'd have an interview with them to talk about it.*

Read *et al* (2005) suggest that the tone of comments may vary depending on the assessor's gender, although their study is less clear about whether gender affects a student's openness to the feedback. The literature also supports other complaints by the respondents; research on student dissatisfaction with feedback includes content, timing, and lack of marking clarity (Higgins *et al*, 2001; Huxham, 2007), as well as inconsistency between lecturers (Beaumont & Shannon, 2011). This account, although seemingly small, remains distinct in the mind of a graduate who felt the downgrading of her work was unjustified:

A2CCF: *I remember doing two weeks of labs, that's four sessions, and getting to the end and the TA's [*teaching assistants*] were supposed to come round and check and[*they said *] it was fine [*but it wasn't*] … and I got docked marks for that which was unfair.*

In my original search for university courses, I had examined the UNISTATS student satisfaction surveys, which included student judgements on quality of assessment and feedback. When discussing original choices of institution, many respondents had not been too interested in this judgement, however, this was acknowledged as a significant omission with hindsight by one respondent:

A1ASF: *I do remember looking at the university league tables where they list student satisfaction, and I know* [Appleton] *is not great for student satisfaction but I think, when weighed up against … Well, it had such a good reputation, the fact that student satisfaction was a bit lower was not so important.*

There was further criticism on the quality of feedback at Appleton, both from undergraduates and graduates.

A1PTM: *the marking was extremely inconsistent, because I felt I had put in the same amount of work for two lab reports. One of them gets 60% and the other gets 75%, and I felt they were of the same quality. So people have different standards… it led to my changing my degree programme within my university.*

This problem with feedback at Appleton was acknowledged at a much higher level within the institution, and the significance of the issue raised on the UNISTATS student satisfaction surveys, were highlighted as a key area for improvement. Thus, the policies for feedback had recently been altered.

A1PTM: *So the department tried to restructure the degree programme for the first set of people who pay £9,000, but rather unfortunately they use the first set as guinea pigs, so did one term with the old system and one term with the new system to see which one they like.*

The demands from the newly fee-paying students now means that universities are obliged to ensure that their 'customers' remain satisfied with all aspects of their course. Crisp (2007) suggests that as students now pay tuition fees, feedback may be considered as something they have paid for, irrespective of whether they intend to engage with it.

The prospectuses had referred to world-leading physicists teaching undergraduates, which understandably implies to potential students that peer-recognised [64] scientists would educate them. It seems that the students, in choosing their place of study, had put their faith into those institutions where success was recognised. The self-regulation of science knowledge is accepted by society to be reliable and indeed, knowledge imparted within the school education system does not question the validity of knowledge from the scientific world (until the scientific world itself gives reason for doubt) (Kogan, 2005; Latour, 1987). It was evident, however, that student expectations of being taught by research leaders did not live up to the reality of being taught by these experts: as many school students will reaffirm, an expert in knowledge does not necessarily make an expert imparter of knowledge.

Not all discussion on feedback and assessment were negative however. Within this field of influence, it has to be acknowledged that positive events play a significant part in influencing individuals. One undergraduate at Einstein gave a far more positive description of the effects of feedback on how he felt about physics:

E1NFM: *And my favourite thing, he said it's all really good, some of the quantum*

[64] Peer recognition is the key to being considered as a successful scientist; there is little argument for scientists being validated (or dismissed) by the layperson in society.

mechanics is wrong but you haven't covered it yet, so that's quite understandable. Yes, so he was really pleased with that and I was pleased that he liked it.

Interestingly, the description of the events below suggests that positive feedback can be powerful enough to alter an individual's trajectory[65]. For this respondent, their reflections indicated that this feedback was enough to change their degree subject:

E2CPM: *I did a* [physics optional] *course, and the assessment that we had to do at the end was an essay and... And I handed it in and the professor was really impressed by it … and that was what made me think, actually, I could do physics at uni, and it might be a better thing to do.*

Ferguson (2011) considers feedback critical for developing learners who are able to regulate their own learning. While providing effective feedback to students can prove demanding for academics (Trotter, 2006), it can be seen from the reflections of the students, that the feedback (or perceived lack of it) influences the respondents' identity with the subject. Negative feedback seemed to have had the biggest impact on the male participants across both institutions, with one respondent getting quite agitated during his recollections:

A2TGM: *another person in my year went up to him and said would you mind re-explaining this and he more or less said are you stupid or something.*

One of the graduates (in fact, a postgraduate physicist) described how he felt when he was having something explained to him that he could not understand. With hindsight, he acknowledges that his expectations of the lecturer were misperceived; however, the significance of the moment and the effects of his identity are apparent:

E2NSM: *I mean they* [the lecturer] *were talking to me and they knew that I was a student in the second year. So I assumed I should be able to understand what they*

[65] Drastically in this case, as the respondent changed from a philosophy degree to a physics degree.

were telling me, because they should be gauging what they should say according to their audience, but I understood nothing and that made me feel terrible.

It is an interesting point to make that this respondent has now rejected his association with the subject and completely changed his trajectory by rejecting his experience at university and physics in entirety. Burke (1991, p. 841) describes how feelings of low self-efficacy and disaffection occur when an individual's behaviour has effects, but they cannot perceive these effects. The negative event described above was significant enough that it altered his perception of 'self', and redefined his competency levels (Carlone & Johnson, 2007). House (1974) also describes how stress is exacerbated when performance does not reflect personal goals, or feedback received suggests an individual is not good enough even though they aspire to be (i.e. their identity says they are good). There may be many other factors for this respondent that remained undiscussed during the interview; however, it was this moment that was recollected as paramount in his experience of university physics: his critical incident.

4.4 Theme 3 – Changing Occupational Aspirations

4.41 Initial Occupational Aspirations

My analysis included an exploration of how the students and graduates, when they first enrolled onto the degree course, had perceived their futures following graduation. Kembera *et al* (2010) found that many students used career prospects as a precursor to choosing a degree, although they also cited interest and positive experiences from studying it at school. I acknowledge that not all students choose a degree for career purposes; Sassler *et al* (2013) describe how some arts colleges promote the virtue of knowledge and learning skills for their own sake, as well as reasoning that those who study science may do so in order to make sense of their world, with little regard for future vocational pursuits. However, for the purpose of my study and my desire to explore whether education events on the physics degree influence the destination of the students, I examined their aspirations at the start of their degree experience. By taking physics at A' level, they had instigated the chain of events that would lead them towards a degree in physics. The students reflected on the factors[66] that had influenced them towards entering tertiary education in the field of physics.

Some interesting differences emerged from the students at the different institutions. For example, not all the undergraduates from Appleton had a planned trajectory at the start of their degree course; instead expressing subject interest as being the main driver for the choice of degree. A recent article by the Economist states that students want all sorts of things from higher education "to make friends, sharpen their minds and get away from home. But most of all they want it to improve their economic prospects" (Duncan, 2015, p. 14). Research by Scutter *et al* (2011) also states that a major factor for commencing any degree was interest in the topic, followed by career prospects. Due to the small sample, this may have been coincidence rather than linked to the institution; however all the Appleton undergraduate students expressed their wish to enrol into a globally recognised physics department.

A1AMF: *When I was younger and thinking about it, it was all about space and rockets.*

A1ASF: *I remember saying in my interview that I was interested in quantum mechanics and nanotechnology. Going for the university that had the best reputation, which has the best experience - I don't mean like socially, I mean academically.*

A1OBM*: I was good at maths and physics and so you go on to study it. Then I chose to do physics at university but it could have been maths or engineering.*

A1PTM: *But you don't really know what your interest is in, if you like atomic physics or lasers, or space. When I was in first and second year I was pretty devoted. I wanted to do physics forever.*

[66] as discussed previously on page 92

The four graduates were more specific about their desire to enter into an academic or research-related occupation at the start of their degrees. This may be because the undergraduates began their degree at the beginning of the global recession, and thus the status of the institution may have been an influencing factor in terms of potential job prospects at the end. All the graduates however, began their course before the recession, when there was less doubt about the future and career speculation could be a positive occurrence.

A2CCF: *one of it was academia, and at the time… I was thinking why doesn't everyone want to be a physicist, or a scientist, or doing natural science or whatever?*

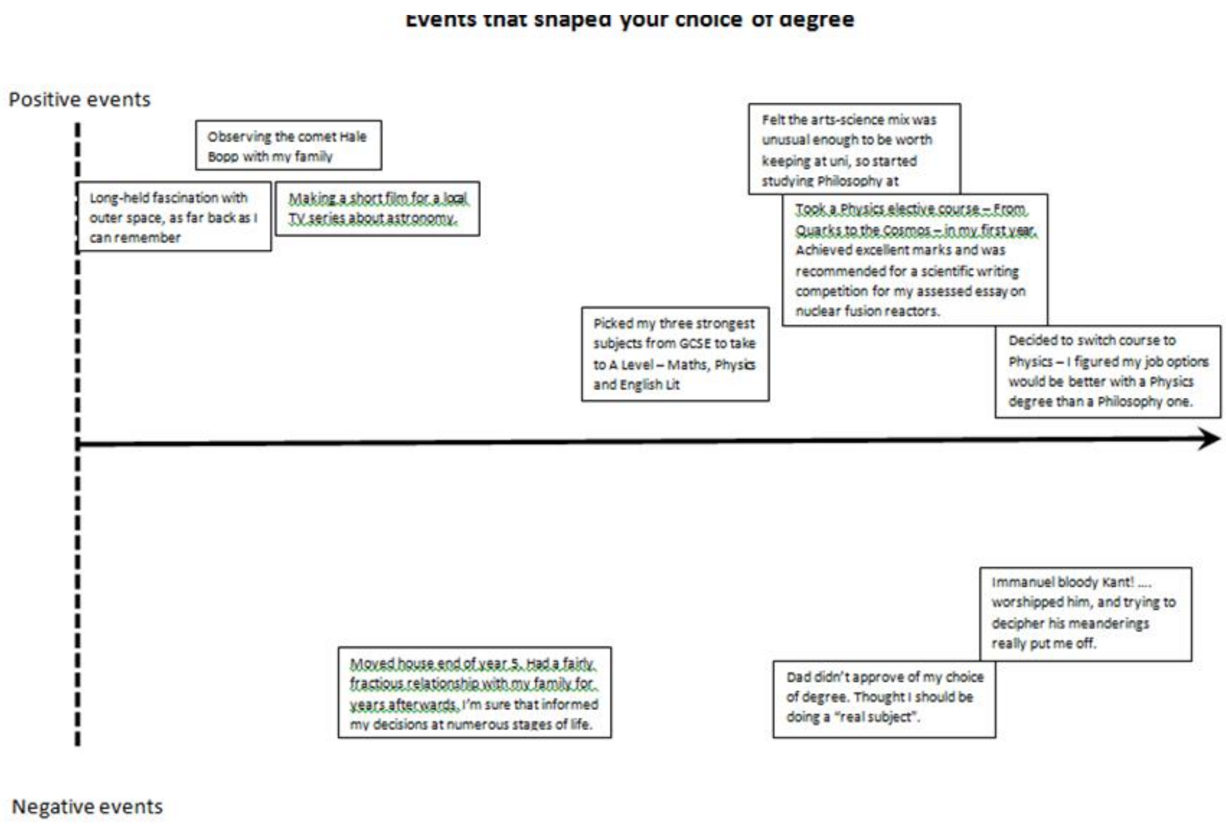
A2TGM: *Well I was still thinking of going into academia at the end of my degree, and I applied for three different universities.*

At Einstein, one undergraduate wanted to enter academia when they began their degree and had applied for postgraduate courses in order to remain on that path. The other undergraduate was less focused, but had a well-defined trajectory emerging by their second year of the degree. Both admitted that they had much more focus to their occupational trajectory as they headed towards graduation.

E1NFM: *When I started my degree, I definitely wanted to continue once I'd finished and do a PhD, and hopefully go into research.*

E1BCM: *Halfway through my second year at university I decided that I liked this teaching thing, I'm going to give it a go, and really fell into it.*

The Einstein graduates had a more long-term view of employment, and acknowledged that their physics degrees would heighten their earning potential. This is evident in the timeline of the respondent E2CPM:



Timeline 8

In terms of changing trajectories, both Einstein graduates both moved away from physics into occupations with little use for the skills learnt over the course of their degree, even though they more vocal about their concerns with job prospects, and indicated that they chose physics degrees because of the occupational potential:

E2CPM: *Because I did an optional course in physics* [whilst on a philosophy degree course] *and it struck me, it might be a better thing to do as far as job prospects when I graduated were concerned.*

E2NSM: *that if I was going to spend money on a university education it might as well be on something I could maybe make some money back out of, rather than less interpretive subjects, as you might say humanities are.*

There is some indication here that the expectations of where a physics degree could take the individuals ranged from heading down the path to academia to the more realistic ideas of potential for earning. This may have been a sample coincidence, but there was to be a noticeable difference in the responses between undergraduates at Appleton compared to Einstein. More research would need to be done in this area to see if there is more impact of recession, or the changing economy is more noticeable by city rather than rural students.

By the end of their degree, many of the respondents had altered their occupational trajectory. There seemed to be a consensus across the undergraduates that they aspired to be recognised as playing a useful role in society. The impression I got was of individuals who, as they had matured, had recognised the role by which they could participate in benefitting wider society. This maturing of identity had allowed them to recognise that their personal goals could be part of a win-win situation.

4.42 ASPIRATIONS TO 'GIVE BACK' TO SOCIETY

There were little institutional difference regarding occupational aspirations, but some gender differences were apparent. All the females from Appleton highlighted their desire to be positive in terms of their relationship with society, recognising that there was a certain amount of 'feel good' in helping others or being useful. The following reflections are all from female s, both undergraduate and graduate responses.

A1AMF: *I would like to be researching, either working in a hospital, or working as a doctor doing research, as an oncologist or a radiologist…doing something useful.*

A1ASF: *Well I've actually got a job with Teach First for the next two years, teaching physics... I'd like it to be something I want to do as a career... I quite enjoyed the feel good factor of explaining things.*

A2CCF: *It's looking less like going down the academic route. I wanted to do that when I started, but after seeing how academia works and how insecure your job is…I really enjoy doing the problem solving and research but the other stuff, the writing of papers and stuff, I'm not happy with that… so I'm going into public education of science, the aim of helping kids.*

There seemed to be less direction with the male students at Appleton: there was evidence of a confidence in potential employability, but their physics expertise was considered less critical in their choices of occupation.

A1OBM: *Now it's just less certain that my interest in physics has to be satisfied by a career in it, or is it something that I'm interested in and would like to keep reading about, but actually do something else as a career.*

A1PTM: *I'll get a job in whatever - I'm not worried about getting a job. If it wasn't physics I'd say something to do with programming. It also might not be just up to me because it's very likely I could do a PhD in theoretical physics and have no job afterwards because there's ten people after the job.*

A2TGM: *So initially, I wasn't thinking about that too much, and then I needed to get a job, effectively to get money in. And basically when you put your CV online with a physics degree, pretty much everything you get is an offer!*

There seems to be a consensus with all the undergraduates at Einstein that having a positive effect on others was a requirement of their future employment.

E1BCM: *Halfway through my second year at University I decided that I liked this teaching thing, I'm going to give it a go, and really fell into it.*

E1NFM: *Because I recently changed from wanting to do particle physics to wanting to* *do atomic physics. To me the difference between the two is that particle physics is such a small field with such a large number of people going into it … It's so competitive and I wouldn't want to be in that competitive environment.*

It can be seen that there is an awareness of the competitiveness of the job market, and a realisation that the physics degree can open up avenues to other domains, such as education. Therefore, although physics plays a part in the responses, it is obvious that the need for employment has significantly influenced their personal goals. This might be seen as an example of the pushes and pulls described by Roberts (2009), and previously discussed on page 31.

This growing competitiveness of the research field, both among universities and between them is concentrating more and more research funding in fewer and fewer institutions, making obtaining research posts more difficult to obtain: In the UK, 80% of research funding goes to just twenty five institutions (Barber *et al* 2013). Seymour and Hewitt (1997) have also noted that the competitive culture of science may influence students' science identities and persistence in the metaphorical 'leaky pipeline' of STEM, as intense competition often drives students away from the sciences. It is notable that some undergraduates emphasised their wish to keep 'doing' physics in their future plans, albeit tempered with caution about competition and lack of funding. This competition may have led to some looking to teaching as a more secure occupation; however, it was notable that the postgraduate with a physics PhD had completely rejected the subject.

E2NSM: *I do work with charities and education groups to teach children technology, I teach green technology to people … it's just a really good tag line – 'Hi, I've got a PhD in quantum physics'…and then I just steer it off into some other direction.*

4.43 Attitudes to financial occupations

It may be just a repercussion of the banking crisis but the responses indicated a fairly negative view of employment in the financial markets. This refers back to the idea of identity being influenced by both positive and negative incidents; in this case, it is possible that external influences (for example, the media) may have had significance in occupational decisions. All respondents discussed employment in the financial corporations voluntarily in interview, with every respondent stating that the allure of the lucrative income associated with such employment was not on their agenda. Most of the respondents implied that they would rather not work for a bank because it would 'feel bad.'

A1AMF: *No not really. I can't imagine myself working in a bank; I've just got too much interest in science in general, new discoveries and things. No, that doesn't interest me at all.*

A1ASF: *That was nice to know, that there was some kind of well-paid job possibility at the end of it. … And with the 2008 crash, it seemed abhorrent to go into finance basically…An endless slog in the City for what would probably be a good salary wouldn't bother me, it sounded like I'd be miserable and wouldn't be achieving much or helping anybody.*

A1PTM: *I don't want to work in the City, for a bank. I want to work for a company I won't feel bad working for. It's quite hard to do that.*

A2TGM: *I knew I didn't want to work in a bank, because they work you like a dog.*

E1NFM: *No, I don't think my family would be particularly impressed and I couldn't live with it. I just think the financial sector is something that upsets me a bit.*

E2NSM: *Finance, absolutely not no, it sounds deafeningly boring!*

It may be that the media storm generated around the financial crisis and ensuing global recession was one of the influences for these attitudes towards working in the financial sector. Mortimer *et al* (2002) stated that occupational choice was highly sensitive to historical and economic decisions, and so although there was evidence of much investment from the financial markets surrounding the Appleton students on a daily basis, the respondents gave definitive arguments against working in finance. Similarly, research by the Association of Graduate Recruiters Conference asked 550 female undergraduates studying STEM degrees about career plans in 2013. The survey found that 38% of those surveyed gave public sector charities, management and consulting as popular destinations, with very few mentioning finance or accountancy (Philips, 2013). Although this survey was aimed at female STEM students, it is interesting that the report noted the unpopularity of finance by their respondents. Equally, the CBI commented on the changing attitude towards finance and banking, with the Telegraph highlighting a report by the CBI and Price Waterhouse Coopers that:

> Graduates no longer want to become bankers …The reputation of Britain's banks has been so tarnished by the economic crisis and recent scandals that the industry is struggling to hire talented staff (Aldrick, 2013).

I acknowledge that my interview sample was only a small set of individuals from the two institutions; nevertheless, the economic recession and subsequent media storm had permeated the educational lives of these students. It will thus become quite interesting to see whether this changing attitude in today's young graduates continues to affect employment in the financial sector in the next decade or so.

Throughout the data collection and analysis, I have been aware that there are the events within the field of influence that is physics education. These are significant in terms of how the respondents adjusted their trajectory over the course of the educational experience. These events are what I consider the critical incidents: along the journey from school to the more experienced individuals near or post-graduation. They are significant because of how they affected the individual; reported through the interviews as activities, reports, feedback and recognition during their learning journey. Looking at the events in terms of the wider social context, it can be seen that they are the critical incidents that go some way to shaping the identity and trajectories of physics students.

4. 5 CRITICAL INCIDENTS AND EMERGING SCIENCE IDENTITIES.

4.51 DEVELOPING SKILLS ON A PHYSICS DEGREE

During the course of this research, I have explored the recounted journeys through a physics degree course by undergraduates and graduates. Throughout their journey, they have matured and developed their skills to becoming practicing physicists. The prospectuses of both institutions market the idea that higher education is instrumental in influencing occupational potential: this is supported by some literature, where higher education "is promoted as a training ground for skill acquisition in which the product of education is a worker, ready to advance the career and earnings of the learner/worker" (Saichie & Morphew, 2014, p. 521). The interviews with the teaching staff also indicated that they wanted their students to develop skills not directly related to the subject:

AXTS: *Definitely an ability to think for themselves and not stick slavishly to what they've been told to do… by the time they finish I hope they'll be able to do things a lot more independently. I'd say it would be unusual for me to be having an eye all the time on what they'll be doing in their final year.*

EXTS: *but not only that but also with study skills, try to teach them to study independently, to study really for its own sake. And to develop some skills that employers value, because we want to get them into the workplace. We want them to think well of [Einstein] and to value their degree.*

4.52 INDIVIDUAL REFLECTION ON IDENTITY

During the interviews, I was aware of that many of my respondents spent some time reflecting on their experiences on their degree, including the moments when their learning all made sense. For many, during the interview, the respondents described this event as 'their lightbulb moment.' These moments are significant as these respondents' were also the ones hoping to keep the subject as a significant part of their future occupations. These events highlighted their reflection on their identity as a future physicist. In terms of the earlier discussion on critical incidents, these moments in time are significantly positive events reaffirming the respondents' identity with physics. In the majority of the respondents, it was these fields of influence (Wenger, 1998, p. 154) produced by the "rich and complex sets of relations of practice" (p. 162) that retained the trajectory towards the positive; a symbiosis with the influencing factors the students engaged with on their course.

A1ASF: *In quantum mechanics I remember having one of those moments when suddenly things linked up with many of my other courses and they just described it in a different way to previous lectures and it all just suddenly made sense and it was wonderful.*

A2CCF: *somebody asked what he thought about the beginning of the universe…, he said quite coolly 'I don't know; as a physicist I'm trained to be happy with uncertainty.' I think that's how it goes with physics – I'm going to get the truth for everything, and ending up with 'I don't know anything!'*

E1BCM: *someone said something that really changed the way I think… they said what you've got to remember is everything we see around us are models, the way we choose to explain things. So when things don't fit our models, we find something new and if it doesn't work, don't think that's something strange. Remember it is just not fitting into with the construction of the universe we've created.*

4.53 Educational influences on identity

There were very few moments during the degree course where teaching methods were highlighted as being memorable; lectures were usually recollected for being 'un-physics like':

A1AMF: *There's one lecturer... He was trying to demonstrate conductivity and electrical hobs and he made us all omelettes during the lecture! That was fun.*

A2CCF: *only he would go to great lengths to make sure the lectures were engaging, with demonstrations. But because he spent a lot of time making sure trying to cement things in different ways in the lecture, he did treat it more like a classroom. So while that isn't university standard I think it did help everyone in first year.*

Both these events were indicated as memorable in terms of the teaching at Appleton. The incidents become significant if viewed from the institutional view. All the events discussed above are, in some way, related to the conceptual understanding of the physics being taught, with the respondents reflecting that the positive incidents had renewed their interest and excitement in the subject, whereas the negative events left them with self-doubt. The respondents from Einstein included very few details of teaching during their interviews; instead, the moments highlighted were almost entirely socially orientated:

E1BCM: *One thing that really stands out would be the days we finished exams, always seemed to be stuck in my mind. They were always beautifully sunny, with the campus's green grass, and outside...*

E2CPM: *Anyway, everyone had a really good relationship with each other, it was good fun!*

E2NSM: *I met really great people; had a really good relationship with all my classmates, and so I tell people, in the future when they're going to university they'll have a lot of fun.*

4.54 Institutional differences on identity

These differences may or may not stem from the fact that Appleton was an institution based in a city, whereas Einstein was a campus-based institution and would have had a more community-based aspect on a daily basis. A recent Institute for Public Policy

Research publication highlighted

> For most of the 20th century (and of course before), being on the faculty of a university meant living and working there, and indeed it was not unusual for universities to require their staff to live within a certain radius of the university. It was a community (Barber *et al* , 2013, p. 13).

The following pages tabulate the changes in trajectory for each undergraduate and graduate interviewed. Although I have discussed many different incidents significant to the individuals, only one incident has been included for each individual. The respondent considered this incident by to be one of the significant moment in defining their occupational trajectory, and a key moment during their educational experience.

I remain aware that a summary is very rudimentary, and even if I were to fill the table with the complete interviews, I would still not have included all the events in people's lives that have preceded their current position. However, having worked intensely with the data, I am comfortable with the notion that the moments included in the table are those that had a significant impact on decisions that each individual went on to make.

Table 3: Summary table of educational pathways

Identifier	Initial trajectory	Respondent's reflection of their trajectory-influencing critical incident on their physics degree (educational incident through identity, attainment or external factors)	Current trajectory
A1AMF	Academia (astrophysics)	**Identity**: I like the idea that when you learn how something works, you can then go on to put it to use.	To work in medical physics

A1ASF	No clear ambition (physics left more options open than engineering)	**Attainment**: We wrote a one-page article [for schoolchildren] to get across the idea interestingly and I did well.	To teach science (physics)
A1OBM	No clear ambition (scientist)	**Identity**: A kind of resilience... being used to being out of your depth. That's the biggest thing; that's what's changed.	To do something that ends up with me somewhere I didn't think I was going to end up.
A1PTM	Academia (general physics)	**Attainment**: I think I've surprised myself as to how much I've enjoyed maths.	To complete PhD in theoretical physics
A2CCF	Academia (theoretical physics)	**Identity**: The thing I remember a lot…is the level of stress. I remember the level of stress was truly awful.	To work in public education or policy
A2TGM	Academia (theoretical physics)	**Identity**: It was a big discreet piece of work and it was yours and you owned it.	Employed in the IT sector (problem-solving)
E1BCM	Academia	**External**: [He said] Everything we see around us, that's the way we choose to explain things.	To teach science (physics)
E1NFM	Academia (particle physics)	**External**: She showed me a lot of the stuff [experimental	To complete PhD in Atomic Physics

		physics] that I'd never taken the time to think about.	
E2CPM	Philosophy degree, switched to physics (job prospects)	**Economic**: I ran out of money and had to take months out to work and earn money to get back in.	Job in IT/ web development (aspiring science fiction author)
E2NSM	Job prospects	**Identity**: I was a really good student, getting great results, and yet I couldn't understand a word he was trying to tell me.	Works with charities and education (non-physics)

From these ten individuals, all of whom have committed themselves to a degree-level education in physics, only two remain committed to continuing in physics based research. Four want to become (or already are) science teachers, an occupation with more security that academia, but not considered a physics-related occupation[67] (Institute of Physics, 2012). Two are employed in small business as IT specialists[68], one sees her future in medical physics and the final one had no idea of occupation at the start or at the end of his degree. Thus, if we take the first year undergraduate (medical physics) and the graduate (IT specialist in a small business), only two out of the tem have continued in physics-related employment. In the final chapter, I will explore what this may mean as we encourage more people to complete physics degrees in order to alleviate the STEM crises.

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[67] The IoP considers teaching to contain aspects of physics but overall is an educational occupation, rather than a STEM occupation.

[68] Although one indicated that this was a stop-gap towards becoming a science fiction author.

CHAPTER 5 DISCUSSION AND CONCLUSIONS

This chapter provides an analysis of the findings presented in the previous chapter and discussion of the implications of the emergent themes. Initially, I will present a diagram summarising this thesis' contribution to the existing research in the field of STEM education. The limitations of my study will be then discussed before I examine how the themes identified in the preceding chapters are significant in the field of science education and uptake of STEM. Following this, my key research question will be addressed: Do the educational experiences on a physics degree play critical part in the field of influences on occupational decisions? Finally, I will suggest areas for future research that may shed more light on the uptake of STEM occupations from an educational point of view.

5.1 CONTRIBUTION TO THE FIELD

Within this study, reflections on physics degree experiences have been analysed to identify emergent themes. As a small, selectively sampled study, the contribution to the field will not be one of generalisation, but a small piece of the jigsaw puzzle that surrounds the field of STEM education. As such, this thesis has examined the fields of influence involving experiences on a physics degree, and has identified several factors that may be pertinent if further research in this area was to be undertaken. In the diagram below, the field of influences surrounding occupational trajectory include some of the literature that has been touched upon but not discussed in any detail within this work. The highlighted circle is the contribution to this field that has been made by the analysis of the interviews discussed in this thesis

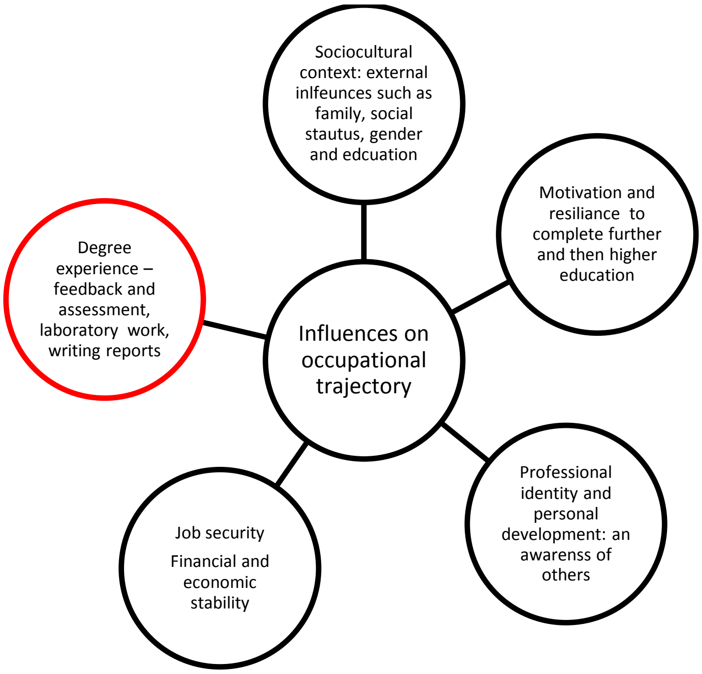

Figure 23 Contribution to the field

5.2 Limitations of this research

Like all research studies, this study has several limitations. First of all, the findings presented here are not meant to be universal. The small sample numbers mean that there is limited scope for generalisation. As the research study involved staff and students from only two universities, and only one subject, the results cannot be generalised to the whole student population. However, because it was restricted to a relatively homogeneous sample in terms of educational level, age and subject, the findings do provide a small insight into the educational events in higher education that are significant to those taking physics degrees. Nevertheless, a single study allows the potential for future generalisation, if similar research with a larger sample population was to be completed. Results from these studies could then be compared and differences and similarities revealed.

Another limitation of my research is that the interview data is a social construction, so a different researcher may have interpreted the transcripts differently. To prevent this from occurring, in as much as I have been able to, I have included the transcript data verbatim wherever I can, to support my analysis. As this was just an exploratory study into the events over an educational journey, the interview data are “representations of lives, not lives as actually lived” (Bruner, 1984, p. 17), and so, although the recollections of experiences are not complete fiction, they have been shaped by the life history and other significant, (but not examined) events experienced by the respondents. This is a further limitation, as my evidence is provided from the sole viewpoint of the interviewee and the data provides only one viewpoint of their experience. However, my study is examining how the experiences has been part the field of influences on the respondents over the course of their educational journey, and so I am really only interested in their narrative as a reflection of those events.

The interview data was transcribed and checked by the respondents prior to the analysis. Thus, there was no opportunity for clarification thereafter, as my coding began after this checking had been completed. As the transcriptions were analysed, the themes emerged that had not always been covered in detail during the interview. Equally, given the relatively small number of interviews, I cannot be categorically certain that issues mentioned less frequently were less important. The relative in-frequency may partly reflect the dominance of other surfacing memories. The different permutations of educational pathways and events for individuals are immense, however the indications in this study allow for future research into the several of the different issues raised, such as significance of laboratory work, with potential for alleviating some of the issues in science education.

This study has identified several key areas in terms of the critical events and formation of identity. The educational journeys for these physics students have involved interactions between the individuals and their social relationships (Giele & Elder, 1998). It is necessary to bear in mind that the individuals interviewed have passed through a specific education policy and labour market condition. The current students have all passed through the transitional stages of a newly fee-paying, post-recessional economic crisis, and the economic burden on them is evident. Although the graduates have not been part of the fee-paying cohort, they have been party to the economic crises; this was already emerging in 2008 (Allen, 2010), before they graduated and subsequently sought employment.

I am hoping that the essence of the respondents' experiences along their journey has been captured to some degree, and with this, new possibilities have been opened up to understand how we can adapt school education practices to resolve the current problems in physics (and science) education.

5.3 Discussion of thematic findings

The analysis has identified some key areas that require further discussion. It seems that from both institutions, there were similar degree course structures involved, with the first two years being dedicated to learning the Core Physics theory. In these two years, it seems that the respondents developed their skills in problem solving, data collection and analysis, as well as broadening their outlook on the world and society.

All the respondents had completed physics A 'level, and their reasons are supported by Rowbottom (2013) who found that students chose A'levels based on finding the subjects enjoyable or providing a good foundation for university courses. Thus, all the respondents had started their degree course with some knowledge of physics. All had an idea about their predicted trajectory at the beginning of the course; to graduate with a physics degree (with the exception of E2CPM, who had started philosophy before migrating to physics); otherwise, there was little evidence of long term planning or goals. In terms of choice of degree course, this seems to be part of what Hodkinson and Sparkes (1997) calls "pragmatic decision-making"

> ... decisions were pragmatic, rather than systematic. They were based on partial information located in the familiar and the known. The decision-making was context-related, and could not be separated from the family background, culture and life histories of the [young people]. The decisions were opportunistic, being based on fortuitous contacts and experiences [...] Decisions were only partly rational, being also influenced by feelings and emotions… (p. 33)

In the majority of cases, the respondents had the ambition of entering research or academia at the start of their degree, a reflection of their enthusiasm for the subject. However, it became evident that this was going to be an unrealistic goal: financial and economic stability were given as two of the reasons. It is evident that over the course of their degree, the reality of becoming an expert in the field would involve too much of an investment of time for a relatively low returns in terms of income and job security. Therefore, it seems that these enthusiastic physics students aim for academia until they discover that the funding arena is hugely competitive. Hence, we see in the sample that those who struggled with stress and finance over their course have altered their trajectory towards more stable jobs.

Research completed by Pascarella (1984) found that university students were strongly influenced by their initial aspirations when they entered the college, and also by the interactions with staff. This may have been the case with the individuals' who struggled with lecturer interactions and assessment feedback; these events may be considered to be negative within the fields of influence, possibly contributing to a trajectory away from the subject.

All the respondents stated their desire to give back to society; to take their knowledge and share it in some way. With such a small sample, it is difficult to say whether this phenomenon had anything to do with the global recession. Out of the 12 individuals interviewed, five saw themselves as either going onto, or already at, work in jobs where they were actively helping others. Two were already signed up to start teacher training courses, seeing themselves as no less enthusiastic about physics than when they started; however the reality of job security meant they altered their trajectory in a direction with more stability and a different expertise. In terms of the sample analysed, there was an equal number of males and females heading for teaching, and equally from both institutions. With the small sample size, we cannot generalise about this in any great way, however for the small sample selected, it seems that teaching and education may have influence the respondents enough to want to participate in it as a career.

The theme that took me most by surprise however, was that of laboratory work. Having worked in secondary school science education for over a decade, I am more than aware of the enormous role that practical and investigation work plays in science education up to Key Stage 4. There was a general sense from all the respondents, as well as the university teaching staff, that practical and investigatory work taught at A' level was not considered to be a principle factor in the course, but seen more as a set of criteria that required checking off before the real exams. Consequently, the level of motivation for experimental work was considerably lower at the start of the university course than it had been during the respondents' pre-A' level course. No final year students at both Appleton and Einstein enjoyed the labs very much, finding them boring and repetitive. I had added the first year undergraduate to the research sample when the final year interviews had all started to indicate a lack of enjoyment in labs. I included her as some kind of comparison, in order to determine whether there was a novelty to first year lab work, which subsequently dropped off by the final year. The first year undergraduate was still enjoying her practical work, but she admitted that she had chosen physics A' level because of the equipment that was used during her GCSE years. She had not enjoyed the practical work at A' level, but in the main had enjoyed first year labs. She was also a little unsure that she had taken the right path, reflecting that engineering had more of a practical application than physics.

An area for further study may be to examine whether A' level physicists who enjoy experimental work enter engineering rather than general physics degrees. Physics A' level is considered necessary to be accepted onto many engineering courses, and so engineering is considered one of the major competitors for physics students. Main (2012) has suggested this possibility, indicating that some (mechanical, civil) engineering and all physics departments demand physics A' level as a pre-requisite for entry on their courses, and so they are in direct competition for applicants. There is some evidence that there are more applications to study engineering at higher levels, as shown by the JCQ and UCAS data in figure 22; however, it is worth noting that this data also includes chemical, bioengineering and material engineers, as well as mechanical and civil engineers.

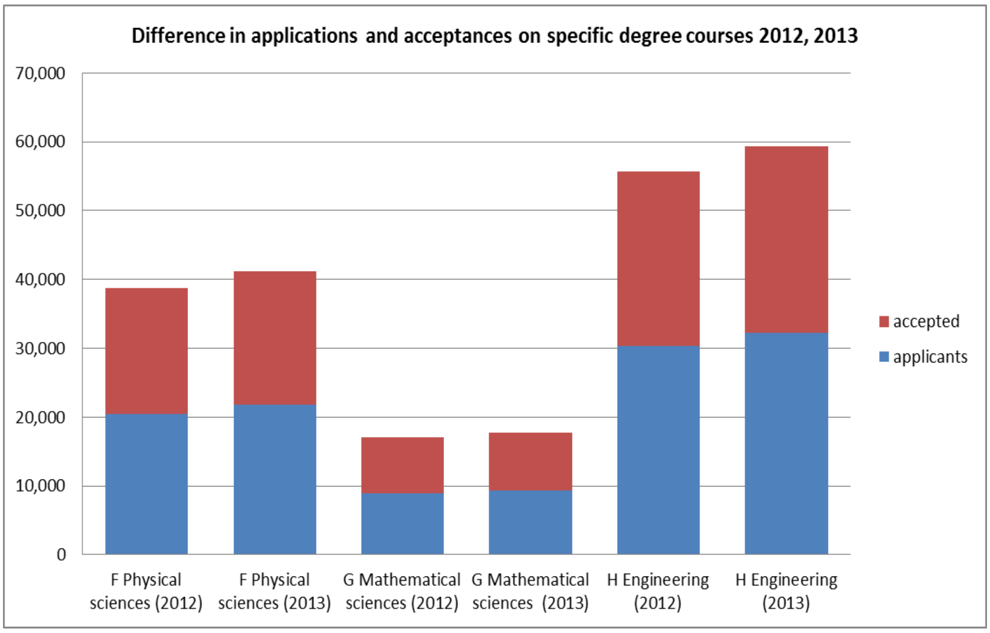

Figure 24: Difference in applications and acceptances on specific degree courses 2012, 2013 (Universities and Colleges Admissions Service, 2014)

Gardner (2013) also notes that aeronautical, civil and mechanical engineering degrees consider maths and physics essential A' level prerequisites, with chemistry A 'level essential for chemical engineering.

As applications for engineering degrees have been increasing, the numbers of students taking physics A' levels[69] have also risen (Exley, 2014a). Data from the JCQ (Figure 25) shows physics A' level entries between 2011 and 2014, with the TES (2014b) reporting that it had risen to the 8th most popular A 'level in 2014. Further research needs to be undertaken to examine the trajectories of engineering students, to see whether their experiences within the educational fields of influence bear resemblance to the ones experienced by physics degree students, especially in terms of laboratory work.

[69] Although the total number of A' level entries fell to 833807 in 2014, almost 17,000 fewer than the previous summer (Exley, 2014a).

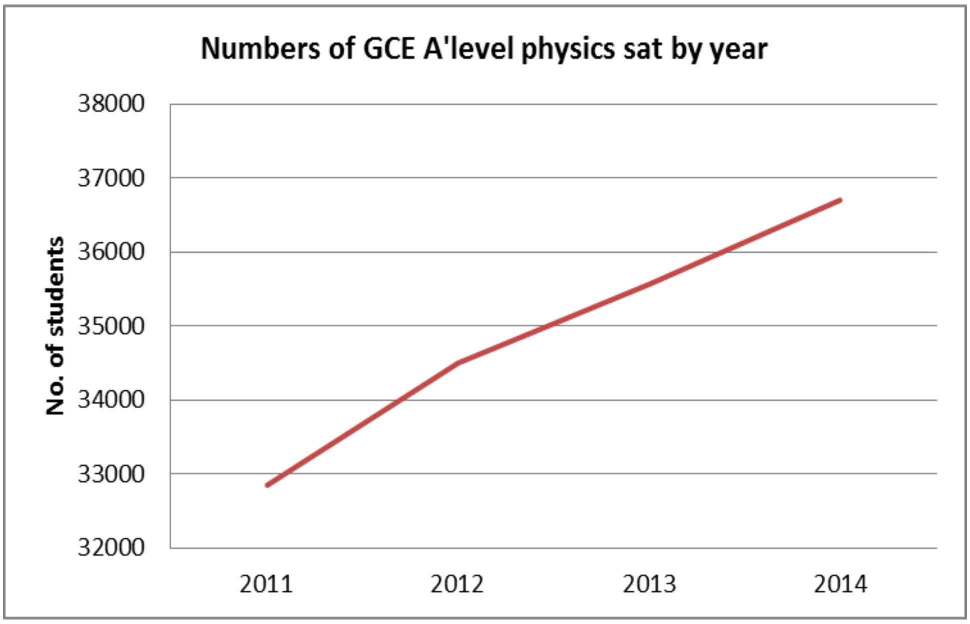

Figure 25: Numbers of GCE A 'level physics sat by year (Joint Council for Qualifications, 2014)

Overall it was evident that the respondents enjoyed the social aspects of the laboratory work; working with a lab partner and supporting each other through the more laborious stages of data collection. There are similarities here to the school laboratory experience, where group-work in experimental science engages pupils (Solomon, 1989). Solomon also notes the social factors in science learning, pointing out that science lessons are "a social activity which is governed every bit as much by the rules and rituals of group activity as by the exposition and questions posed by the teacher" (p. 126).

5.4 Discussion of the findings in the context of education

5.41 The significance of school practical work

Science has a huge responsibility to teach people about the nature of science, scientific methods and how scientists work. Woolnough (1988) argues that school science should prepare students to both live in a scientific democracy and prepare them for work in a scientific world. He argues that a neglected area in the school curriculum is showing authentic science as a messy, problem-solving activity. Woolnough argues that including this would develop knowledge as well as science skills. There are continued rumblings of discontent from various arenas of science education research, where it is argued practical work has questionable benefits (Gallagher, 1987; Hofstein & Lunetta, 1982). Clackson and Wright also note that “although practical work is commonly considered to be invaluable in science teaching, research shows that it is not necessarily so valuable in science learning” (1992, p. 40).

In his book, Practical Work in Secondary Science, Abrahams (2011) investigates the necessity of practical work in science teaching, presenting evidence that it may not have a significant effect on achievement when compared with theory-based teaching. He argues that there is a simplistic, but prevalent assumption that fun and impressive practical work necessarily and automatically leads to effective learning in science. He suggests that students only recall the novel features of a practical rather than the concepts being covered. Kirschner *et al* (2006) also argues that guided instruction leads to better learning outcomes, and it is incorrect to assume that that learning about the subject is the same as learning to do the subject: “Thus the practice of a profession is not the same as learning to practice the profession” (2006, p. 83).

Taber (2011) argues that science teachers want to retain experiments because it helps teach about the nature of science and 'how science works'. He stresses however that despite so much time being spent doing ‘experiments' in UK schools, most students have disappointing ideas about the nature of authentic science. This emerged in my interview data as the respondents spoke of grappling with concepts of precision, repetition and accuracy during their laboratory work. Many school science experiments currently are used to demonstrate a concept, which in fact make them anything but experiments. Taber suggests that school science needs time to allow students to undertake authentic enquiry, working over extended periods to get a feel for the experimental method. For those who have chosen to take science to higher levels, there is currently opportunity for A’ level students to participate in more authentic science projects, such as the Gold Crest Award from the British Science Association (2012), but this relies on schools having links with industry, and enthusiastic teachers willing to give up precious time. In most cases, this type of ‘authentic science’ is not evident until undergraduate levels, when students are allowed limited freedom on first-year projects. It was evident that the interviewees valued their final year research project as discreet piece of work '*and you owned it'* (Interviewee A2TGM).

Prior to A' level, Taber suggests practical work in science could be planned around demonstration and questioning to prompt learning. This would then be connected with appropriate writing tasks to develop writing skills. The argument against this, however, is the study by the Institute of Physics, who "applaud the excellent work carried out by school physics teachers" (Sneddon *et al*, 2009, p. 1128). They specify that students revel in the more open-ended experimental work and this needed to be addressed. There is concern however, that without reducing the curriculum content, time would still be a constraining issue.

This argument suggests that the improvement would be to teach science as a theoretical construct, rather than engaging with practical work. There are dangers to this view however, that students not engaged will have no 'hook', and equally, more able and potential STEM candidates will not develop the necessary manual dexterity to use science equipment at higher levels. There is further evidence of these dangers in a survey by Cerini *et al* (2003), who found that for 71% of 1400 students, practical science was considered the most enjoyable part of school science, with 38% claiming it as the most useful method of learning science. Thus, as nicely summarised by one of my respondents, science lessons were memorable when they included:

The things that surprise you in class, the stuff that sticks with you, are the little experiments that give you results that you wouldn't expect.

(E2NSM, male doctoral graduate, 2014)

The interviews suggest that more work needs to be done in schools so that the university laboratory experience has a better foundation. This means that there is a requirement for investment in school level education in order to enhance the experience of laboratory work in science. The interview data suggests the problems with laboratory work begin at A' level; there is pressure on teachers to get students through exams, rather than develop their practical skills. This is further confirmed by an Institute of Physics study that stated in A' level physics, "the focus of their practical work was often more directed towards the needs of the practical examination that they had to take" (Sneddon *et al*, 2009, p. 1128). The same study also supports the interview data that as students, they highly value opportunities to take part in active research.

Further issues in school science are noted by Abrahams *et al* (2014), who describe the widespread practice of 'recipe' style practical work, based on demands from curriculum and examination targets (Donnelly *et al*, 1996). A study completed on Australian physics and engineering undergraduates also found a similar issue with laboratory work (Bhathal, 2011). This survey found that the majority (86%) of the first year undergraduates preferred to have written instructions for their physics experiments. Bhathal argues that this may perhaps be due to a lack of confidence in designing and doing the experiments independently, and suggests that this may be a consequence from school physics practical classes. One of the statements made by the lecturer at Appleton, who describes, supports this:

AXTS: … Nobody sees the weaknesses and difficulties. And I think one of the things students don't like about labs is that they're in an open environment – and we try and make it nice by having demonstrators there to come and ask them questions but, in a sense, what they really want to do is understand it on their own. They don't like asking questions, they don't like to be asked questions at times when they're not understanding things and so I think the lab environment doesn't let a lot of students learn in the way they'd like to.

5.42 The authenticity of science education

From the perspectives of the interviewees, there may be a mismatch between the reality and expectations of real life science that has been developed through their secondary school science education. It is acknowledged that teaching school science to reflect the processes of authentic science is difficult, as there are various views of what constitutes real life science (Martin *et al,* 1990). As Bencze and Hodson (1999) assert, authenticity in science is an elusive problem, with many meanings and curriculum interpretations. In order for something to qualify as authentic, the Oxford Dictionary (2012) suggests that it must satisfy some basis that it is of undisputed origin: "made or done in the traditional or original way, or in a way that faithfully resembles the original." Martin (1990) describes how the view is authentic in the sense of the Greek root *authentikos* if it arises from a primary or first-hand experience of science. Hence, it is concluded that authentic school science should provide an experience that is in line with the sorts of activities that occur in the real world of science.

This is where the lack of authenticity becomes a shortcoming within the science curriculum. Within primary and secondary education, there is little authenticity of science investigation and enquiry. The knowledge that we, as science teachers, impart lacks the authentic nature of discovery that fills the time of so many practicing scientists. The widespread use of recipe-style tasks has been observed, maybe because teachers want students to produce the desired phenomena successfully in a relatively short period (Abrahams & Millar, 2008). It is Abraham's view (2008) that lesson time is wasted on giving instruction and tidying up, with too little time spent on the concepts. Atkinson and Delamont (1976) argue that teachers find themselves engaged in ensuring that pupils' investigations meet expected results using appropriate methods. Their description of science education seems to infer that there is very little exploration in a school setting; instead, it consists of the observation and measurement of basic phenomena and relationships. Nadeau and Desautels (1984) argued that:

> By giving insufficient thought and attention to the nature of scientific knowledge and the conditions under which it has been developed, science teaching reinforces beliefs and myths that are inherent in scientific ideology (p. 8)

Hodson, (2008) indicates that that school science continues these five myths[70]: "naive realism, blissful empiricism, credulous experimentation, blind idealism and excessive rationalism" (p. 31). Allchin (2003) also concludes that misleading conceptions of science continue to be promoted:

[70] Based on the work of (Nadeau & Desautels, 1984)

> *Monumentality*: scientists appear as 'larger-than-life' heroic figures; *Idealization*: complexities and biases are absent; *Affective drama*: the excitement and emotional elation of 'discovery' are exaggerated; and *Explanatory and justificatory narrative*: conclusions are seen as unchanging and correct (pp. 341-347).

This problem with authenticity and the real world of science is not being represented in the classroom has been acknowledged by the UK governments and many others (Chinn & Malhotra, 2002; Driver *et al*, 1996; Roth, 1995; Ryder *et al*, 1999). My professional experience confirms that there is little room, or time, in science education to provide what could be considered as an authentic experience of science. The English science curriculum has sought to combat this omission by incorporating assessed coursework into the examination criteria, as well undergoing several changes in attempts to develop a school science that reflects the messy nature of authenticity (Martin *et al*, 1990; Hodson, 1998). This drive for a more authentic approach to science education was addressed in 2004, when the National Curriculum was changed as a result of the *Beyond 2000* report by Millar and Osbourne (1998). This report highlighted a tension in the aims of school science: instead of grooming elite of students for future careers in science, science education needed to provide all students with the opportunity for scientific enquiry, as well as understanding of the nature of science in society. The recurrent changes in the science curriculum[71] reflect a changing attitude towards science by society.

[71] It is nicely illustrated by Carr:

> The relationship between curriculum and society is always reciprocal. Curriculum questions about what to teach and how to teach it, are a particular expression of political questions about which aspects of an existing form of social life ought to be reproduced. Conversely, political questions about how society ought to be changed and improved always give focus and direction to curriculum questions about what should be taught and learned. Curriculum development and social change are thus indivisible parts of a single dialectical process through which curriculum and society are simultaneously reproduced and transformed. (1993, p. 1)

5.43 The changing nature of the UK science curriculum

This reciprocation between science curriculum and society seems to be lessening. As discussed at the beginning of this thesis, there remains a demand from employers for more skilled STEM labour available in the graduate market. There is also a great deal of institutional investment aimed at encouraging young people into STEM occupations.

A comparison between the science curricula of England compared to other countries (see Appendix G) found that most science curricula emphasise the importance of encouraging pupils' curiosity about the world and take a broadly constructivist approach to science as building on existing knowledge and understanding. In England, science is widely regarded as a practical subject, with evidence from the TIMSS 2007 (2008) study supporting this; indeed it highlights that practical science was a particular strength of the English science education, with pupils experiencing high levels of practical work compared with other nations (Department for Education, 2012b). The Department of Education has also emphasised science as a practical subject with students needing an "authentic experience" of what it means to work as a scientist (2011b). It is clear however from the interviews with the students, and supported by the literature (Donnelly *et al*, 1996; Abrahams & Saglam, 2010; SCoRE, 2008) that young people are not getting that experience.

Recent changes to secondary science curriculum have further reduced the practical content to focus on examining knowledge. On 20 January 2011, Michael Gove, the now former Secretary of State for Education, announced the review of the National Curriculum in England. In his speech to the Royal Society, he described the new National Curriculum as "an exercise in intellectual liberation," indicating that it would include "a stronger focus on the importance of scientific knowledge and language and a greater emphasis on the core scientific concepts underpinning pupils' understanding" (Department for Education, 2013, p. 5). There have been signals that the assessed coursework will be removed from the syllabus (Gove, 2012), which suggests a contradiction between both Governmental aims of providing a realistic view of what science is, and the demand for examination-based evidence[72]. Gove has argued that:

> We want to remove controlled assessment and coursework from core subjects...In each subject area only one exam board will offer the new exams…We plan to call these new qualifications - in these core academic subjects - English Baccalaureate Certificates…This coalition is modernising our exam system so we can have truly rigorous exams, competitive with the best in the world. (Gove, 2012)

There is also widespread concern that the new reform to science A' levels mean that assessment of a pupil's practical work in sciences would no longer count in final grades. In November 2014, the House of Commons Science and Technology Select Committee requested the Government rethink the assessment of practical work in the sciences at A' level (Miller, 2014). The Science Community Representing Education (SCORE) has also voiced concerns to the proposed changes, highlighting that they would mean that A' level practical work would be devalued (2014). SCORE cautions that:

> Universities might ignore the result in practical assessment. If that were the case, the priority given to carrying out and resourcing practical work in schools would be reduced. This would prevent malpractice by discouraging any practice at all. And that is not acceptable, as it will leave students even more poorly equipped for progression to higher education and employment. (2014, p. 3)

5.44 The significance of literacy training

Report writing was also significant within the fields of the physics degree, although it was notable that the female respondents were more positive about this than the males. Interestingly, the only male who stated that he enjoyed report writing had already chosen to become a science teacher and was already engaged with educational pedagogy. Those that had really not enjoyed both laboratory work and report writing had chosen to follow the more theoretical route, avoiding the need for either and focusing instead on computational skills. This was in contrast to their earlier selves, where they had described their engagement with the subject through

[72] The foundations for many of Michael Gove's policies are reflected in the book Seven Myths about Education, (Christodoulou, 2014)

the desire to see how things worked and their love of taking things apart. This desire had been eclipsed by their experiences, although I acknowledge that the educational experiences may not have been the main influencing factor. I do not wish to assume causality within this small study[73], but the negative experiences of laboratory work had been within the field of influence of the degree experience and so may have had a contributing effect.

The Institute of Physics report highlights that "having to write up [school science] experiments was unhelpful because it was time consuming although they did admit that they learned from the experience" (Sneddon *et al*, 2009, p. 1128). It is evident from the interview data that some time needs to be invested in the skills of scientific report writing. It may be that if formal report writing is given some importance during a school education, it may become easier to engage with it at higher levels and strengthen the reasoning for its formalities. The focus on writing up laboratory reports is missing from GCSE work, although it is touched upon by the Individual Skills Assignments (ISAs)[74]. However, it is widely acknowledged that the ISAs are seen as a criteria for passing examinations and do not incorporate any kind of rigour or depth of analysis necessary to fully appreciate the science being completed. In particular, they have less rigour in terms of the experimental skills required by a novice scientist.

It is my belief that science education can still be heightened by experimental work in schools; failing that, it may be more appropriate to rename the subject 'the history of science', as that is a more honest description of what is taught: what we know and how we found it out. It may be a way forward to allow the earlier years in secondary school the opportunity to experience authentic science; with extended projects or similar, non-examined, but recognised opportunities for younger people to use science to explore a self-generated question. There is some focus on the career opportunities that physics brings at this stage, but there needs to be a greater emphasis on physics' application to society and the more human side of the subject.

It is obvious that A' level lesson time is limited, hence bringing back the focus on repetition and precision to higher level GCSEs (or their equivalent) might allow

[73] Nor would I want to imply cause and effect for any of the themes discussed in this study.
[74] The ISAs (internally assessed coursework) are due to be removed from the formal curriculum in 2016.

those wishing to pursue science to a further level the experience of authentic method. Furthermore, the experience, and reasons for the formality of report writing could be emphasised at A' level, giving guidance along a shallow incline to those who choose science as their trajectory.

5.45 Educational experience and science identity

The final incidents explored in the interview data were those relating to the development of a science identity and trajectory. It seems evident that during their time at university, the individuals had diverged from earlier trajectories. With their increasing maturity had come a more intensive self-reflection about how they saw themselves fitting into the wider social world and employment. Furthermore, although possibly influenced by the concurrent rise of social media and the omnipresent media, all the individuals interviewed displayed empathy towards society and social needs. It was evident that for some of the respondents, their educational experiences had influenced how they identified themselves in relation to physics. This study cannot claim any cause and effect between the field of influences explored and shifting trajectory, but the incidents highlighted by the respondents may have borne some influence through an accumulation of events.

In terms of the respondents from Appleton, the events I have highlighted as critical incidents are split between those relating to an alteration in their perception of their own identity and those who recognised an aptitude where their attainment had been externally recognised. There was a degree of resilience fostered at Appleton, indicated by the sheer determination to achieve academically when the individuals first began their degree. Although they all anticipated remaining in physics, only a single respondent wanted to remain in physics by the end of course.

At Einstein, the external influences seemed to have a greater influence on the trajectories of the respondents. Financial demands and social interactions were significant fields of influence, and were discussed by the respondents as important in their changing trajectory. As in Appleton, only a single respondent wanted to remain in physics. There were only two respondents seeking to remain at the cutting edge of physics; the majority were aiming for broader occupational roles outside the narrow focus of physics. Arguably, it may be that limited research positions and competitive funding have influenced decisions to some extent; however, I got the general sense from these 'non-continuing' respondents that they saw physics as part of their broader commitment to science, and felt that educating others would be a more reciprocal use of their degree expertise. Thus, it can be argued that they have not been lost to the subject, but in terms of Government and industrial demands for more STEM graduates, they are not available for physics–related occupations. Dabney and Tai (2013) have reflected this in their work on female physics graduates, finding that factors including a perceived lack of time led to individuals choosing occupations based on education or civil service for a better work-life balance and job security.

It is also important for physics to be related to the wider world, not just in terms of physics-related occupations. It needs to be made more human, so that it becomes a subject that is associated with helping others and beneficial to society. Historically, physics has been seen to be a very individual subject, removed from the rest of the world (Kogan, 2005). There has been a rise in more applied science degrees, such as food science, sports science and forensic science; it may mean that the restricted curriculum of the physics degree needs to find some compromise between the constraints of the Institute of Physics accreditation and the 21st Century desire for a relevancy to societal needs. As contemporary society has become more inclusive, and so physics needs to show that it is a reciprocal part of society. Student A1AMF highlights this with her wanting to put what she has learnt to good use; similarly A2CCF and E1BCM both want to give something back to society.

Here I revisit the main research question: do the educational experiences on a physics degree play critical part in the field of influences on occupational decisions? There is evidence that educational events do influence the destinations of the graduates; it was evident that there are educational incidents that encourage or discourage the individual along certain pathways. The students are all individuals embedded within a complex social and cultural network (Giele & Elder, 1998), characterised by shared values and expectations (in Bourdieusian terms, a shared habitus; Bourdieu, 1988). Networks of social connections have influenced their actions, and the data shows the integration of these actions within the fields of influence during the physics degree. Some have shown discontinuities, such as E2CPM who switched degree course to join physics, and E2NSM who rejected physics following a post-doctoral post. Others have smoothly laced together attainment with social and cultural expectations, such as E1NFM, who has continued on his expected trajectory towards academia.

The analysis of the interview data has shown that the two institutions both expect their physics students to continue on their trajectory to acquiring a physics degree. Occupational decisions however, have been influenced by the interactions and delivery of their degree course; they have experienced laboratory work, report writing, and a small experience of 'authentic science'. The question that then arises, and one that cannot be answered with such a limited study, is whether their occupational decisions are down to the degree, the individual, or just a consequence of maturity?

The results of how trajectories change in light of a degree course are ambiguous, mainly due to the limitations of my sample numbers. I would not want to suggest any causal effects or generalise on their destinations for this reason. However, what makes interesting reading are the changes in the trajectory between the start and the end of the degree course. The early aspirations at each institution only differed between two students at Appleton who had no clear ambition towards future job prospects, and two from Einstein took physics because it enhanced job prospects. Out of the ten individuals interviewed, six of them began their degree wanting to enter academia to continue their passion for the subject, possibly reflecting their nativity about professional physics opportunities. The unanswered question remains, would they have taken up this degree if they had known this beforehand?

5.5 Implications for policy and practice

The findings of this research are significant for all associated with science education, including schools, higher education and policy makers. There may be a number of different stakeholders may be interested in the findings of this thesis, and may be able to use them to develop interventions to encourage and promote retention in the STEM subjects. For example, it may be that educational policy makers will be interested in developing the experimental skill set of potential scientists, especially in the provision of more opportunity in authentic research. School educators may want to examine possibilities for acquiring equipment that can be utilised by future scientists. Physics outreach departments[75] may be interested in supporting authentic research projects with school students wanting to engage with higher levels of science. These will also raise awareness of physics in society, although it may become necessary to incorporate more emphasis on the *need* for physics by society to enhance the uptake in physics degrees.

This enquiry has grown out of the real situation based on the perceived crisis in STEM graduates, and so in completing this study I am hoping my efforts can be combined with the many studies that have already explored this area, but using a variety of different approaches and directions. I am hoping that this study will contribute, albeit in a very narrow way, to the national and global discourse on education and identity formation, in the context of STEM and physics occupations.

[75] Outreach departments already support many STEM activities in schools, using grants from the Institute of Physics, Science and Technology Facilities Council or Royal Society, but many of these are short term or daily activities. (Institute of Physics; Science Learning Centres, 2010)

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APPENDICES

APPENDIX A: LETTER REQUESTING PARTICIPATION

Professor XXXXXXX

Head of Department

Department of Physics

Dear Professor XXXXXXX**,**

I am seeking permission to include XXXXXXX in my case study of the student experiences on physics degrees.

The working title for my study is *A critical examination of university physics degrees and the experience of undergraduates*. I am examining a selection of physics degree courses around England in order to analyse how they may influence the final career destinations of graduates.

I hope to interview a teaching member of your Department in order to acquire some depth about the options for physics degree courses at XXXXXXX. I hope that in contacting you, you may be able to identify a course leader who may want to particiapte in my research. This would be followed by more in depth intervews of approximately an hour each with three of your final year undergraduates.

If it would be possible for your Department to participate in my study, I would very much appreciate it if you could send me an email to XXXXXXX. It will be possible to hold these interviews over the phone if necessary, however it is my aim to visit all the universites in my study in person. To that end, if there are any dates or times that are preferable to your Department, I will do my best to ensure that I time my visits accordingly.

All individuals will be given an information sheet outlining the project and a consent form prior to participation. They will also have the option of withdrawing at any time without giving reason.

My study has been reviewed and approved by the Social Science Cluster-based Research Ethics Committee at the University of Sussex (Ref: ER/AJH52/1)

For further information, please contact my main supervisor, Professor Colleen McLaughlin

If you have any concerns about the way in which the study has been conducted, you should contact Professor McLaughlin in the first instance.

I hope that you will allow me to conduct this research in your Department at XXXXXXXX

Appendix B: Email for Volunteers

Dear physics student,

I am writing to request your help in my doctoral research. I am a secondary school physics teacher undertaking doctoral research into how the experiences of students doing a physics degree influence career identity.
In terms of the larger picture, I am hoping that my thesis will support developments in secondary school (GCSE and A' level) physics education.

I am looking for final year physics students to interview as part of my research.
This interview would take less than one hour, and could be completed in person or over the phone (or Skype). I wold be asking you about your educational history leading up to your degree and your hopes and expectations following graduation. The interview would be recorded and the transcription sent to you for checking. At any time, you could request to withdraw any or all information. All your details, as well as those of your university would ultimately be anonymised as part of the data in my thesis (which of course you would have access to following completion).

I very much hope that you will consider participating in my research. If you would like to take part, please email me at:
alexandrajholmes@gmail.com or a.holmes@davison.w-sussex.sch.uk

Kinds regards,
Alex Holmes

APPENDIX C: PARTICIPANT INFORMATION SHEET

University of Sussex

Study title (working title)

The experience of a university degree course: a case study of student perceptions.

Invitation

You are being invited to take part in a research study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

What is the purpose of the study?

The purpose of the study is to explore experiences on undergraduate physics degree programs that contribute to destination choices of physics graduates.

Why have I been invited to participate?

You have been selected from the XXXXXXX to take part in this study. There will be a total of three final year undergraduates asked to participate in in-depth interviews.

Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason.

What will happen to me if I take part?

You will be asked to take part in an interview which will focus on your individual experiences during your school and undergraduate science education. This interview will be recorded on audiotape and transcribed as part of the study. You will have opportunity to read the final transcription before the data is analysed.

What are the possible disadvantages and risks of taking part?

The disadvantage of participating in this study involves a loss of time (maximum 1 hour).

What are the possible benefits of taking part?

The benefits include an understanding that your participation will further our understanding of how experiences at university contribute to the destinations of physics graduates. It may also have some direct benefits to you as a practising physicist in understanding how the degree process influences the formation of identity.

Will what I say in this study be kept confidential?

All information collected about you as an individual will be kept strictly confidential (subject to legal limitations) Confidentiality, privacy and anonymity will be ensured in the collection and storage of research material through the use of password protected documents. Any publication will use only anonymised individuals and places.

What should I do if I want to take part?

If you wish to participate in the study, please fill in the consent form and return to Alex Holmes, Science Department, Davison High School, Selbourne Road, West Sussex BN11 2JX or email alexandrajholmes@gmail.com

What will happen to the results of the research study?

The results of the research study will be submitted to the University of Sussex, Education and Social Work Department, as part of a Case Study for a Doctorate in Education. The results will be a part of a final thesis. I will inform you of the title and how to obtain a copy of the published research through the University of Sussex.

Who is organising and funding the research?

I am conducting this research as a student at University of Sussex, Education and Social Work Department.

Who has reviewed the study?

My research has been approved by a Social Sciences Cluster-based Research Ethics Committee (C-REC).

Contact for Further Information

For further information, please contact my supervisor, Professor Colleen McLaughlin. If you have any concerns about the way in which the study has been conducted, you should contact Professor Colleen McLaughlin in the first instance.
Thank you for taking the time to read the information sheet.

APPENDIX D: PRE-INTERVIEW QUESTIONNAIRE

I would like to record your experiences of your Physics degree and how your thoughts and feelings have changed over the lifetime of your degree course. I would like to understand this in the context of your life history and present circumstances.

Questionnaire

1. What was your age last birthday?

< 19 ☐

20 – 29 ☐

30 – 39 ☐

40 – 49 ☐

50 + ☐

2. Have any of your family studied science to a higher level? If so, please give details.

……

3. Thinking about your secondary school education, was your school…

State comprehensive (or secondary modern) ☐

Independent (private) ☐

Voluntary aided (Church etc.) ☐

Other –please state …………………………………………… ☐

4. Has there been anyone who has significantly influenced you to pursue physics?

Yes No ☐

If yes, can you say who…………………………………………………………………………….

5. Did you complete your further education (A' levels) at the same school you completed your GCSEs?

Yes ☐ No ☐

If no, did you attend?

A different school with a sixth form ☐

A sixth form college ☐

An FE college ☐

Other – please state ……………………………………………

6. What kind of Science GCSE/O' level did you complete?

Double Award/Coordinated/Combined ☐

Separate Sciences: ☐

Biology

Chemistry ☐

Physics ☐

7. What grade did you get in your Physics A' levels? AS……………A2……………………..

8. On a scale of 1 – 4 (**1 being most and 4 being least**), how much do you enjoy…?

	1	**2**	**3**	**4**
Present work in front of an audience				
Solve mathematical problems				
Read a novel				

9. On a scale of 1 – 4 (1 being worst and 4 being best), how would you score yourself at…?

	1	2	3	4
Engaging an audience				
Solving mathematical problems				
Playing a musical instrument				
Playing team sports				

10. Please finish these sentences...

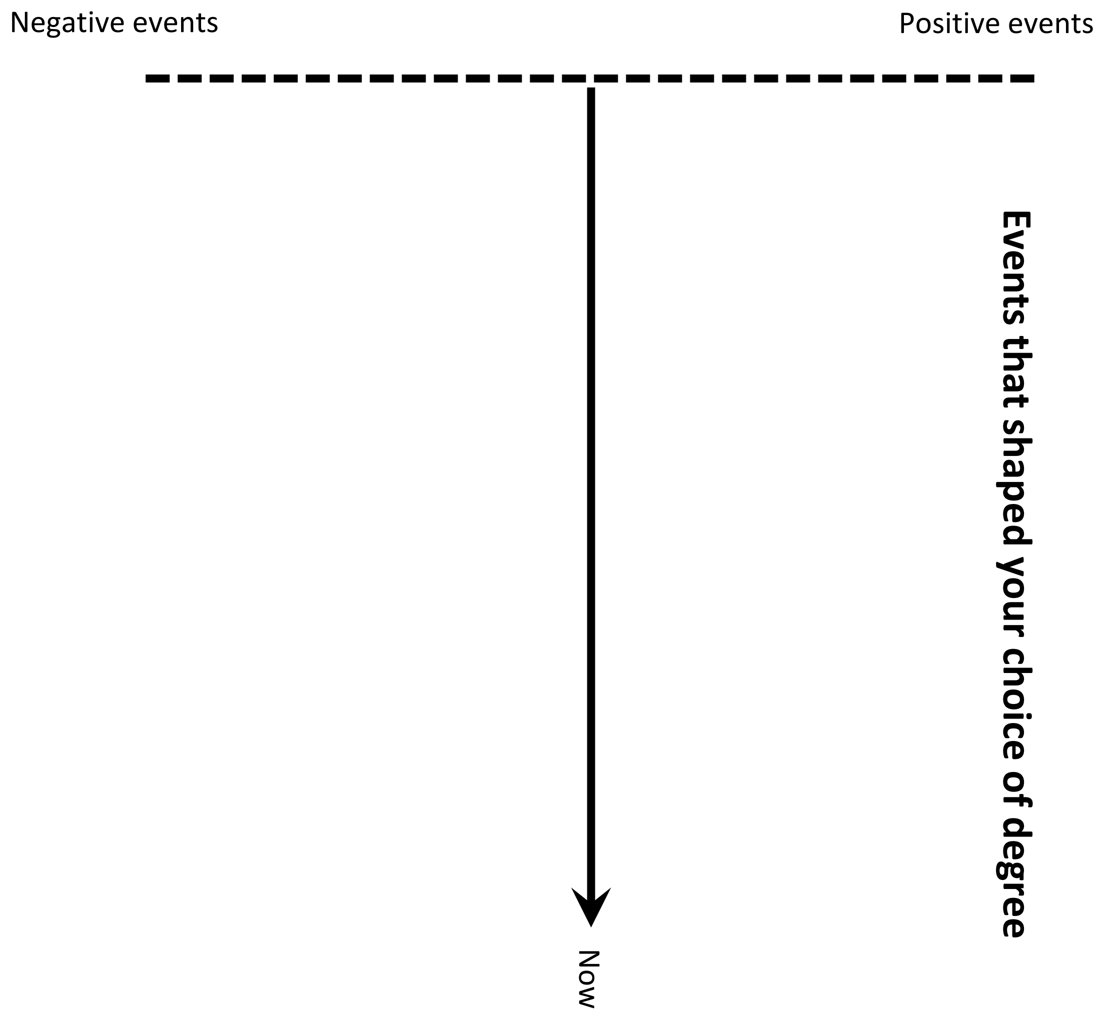
When I was 10, my ambition was to be …………………………………………………………….

Now my ambition is to ……………………………………………………………………………………..

Appendix E: Timeline

Everyone has a life story. I would like to show you this timeline. This will become a summary of one part of your life story, your physics degree. You can see there is a positive side and a negative side, and you can just write into the side you feel is most appropriate. The higher up the page it is, the more positive you believe the event was; the lower, the more negative. During our interview, we will discuss events, people and places that might have some influence over your experience of your degree and if you remember anything, feel free to add them into your time line.

Before we start, can you think of any moments during your life that you think might be significant to your degree? You can begin at whatever age you like and include whatever you wish. Can you jot them down on the timeline please? Here is a pen; it does not have to be neat.



APPENDIX F: INTERVIEW SCHEDULE

Thanks for completing my questionnaire and the timeline.
Also, thanks for allowing me to interview you today. I hope I am not causing you too many changes in your day.
During the interview, if you think of anything that you want to add to the timeline, please just go ahead and amend it.

Is it okay that I record our interview? [Show dictataphone and explain how it works to switch on or off]. Our interview will be a conversation and you can switch off the recording at any time you do not feel comfortable. I just have to clarify that you understand that everything you say will be treated confidentially. The recordings will be transcribed and you will be able to read the transcriptions before I do any analysis of them. You will not be identifiable at any point during the analysis or final piece of work. The recording will be destroyed after transcription.

General probe techniques

Silent probe/pause
Encouragement – I see; go on
Immediate clarification: I am not sure I got that exactly, can you explain a little more fully/ can you explain that to me again?
Retrospective clarification: previously you said to me, can you explain that to me a little more fully in light of what you have just told me?

1. I am interested in finding out more about the experiences of people like you doing physics degrees at different universities. Do you think there were things that happened in secondary school or during your A' levels that might have influenced you to take physics degree?
   Prompts:
   - Do you remember anything that your teachers may have said or done?
   - Were there any good or bad lessons that stick in your mind?
   - Did many of your school friends take similar subjects to you?
   - What did your parents think of your choices?
   - What about TV and the media; can you remember watching anything that caught your imagination?
   - Could you see yourself going onto do a specific thing or have a certain career?

Can you remember if you found out what kind of salaries were available to people with physics degrees?

2. Thinking back to when you first applied on your UCAS form to do physics, why did you choose to do your degree at this university?
   Prompts:
   How many universities did you visit?
   How did you hear about this course?
   Did you look for specific things that were being taught?
   Did the location of the university matter to you?
   Did anyone or anything specifically recommend the course (or the university?)
   Did you know anyone else at the university (on the same course or just same location?)

3. I'd like to get a clearer picture of the things you most looked forward to in the first year When you first got your timetable in your first year, can you recall what you thought about the courses you had to go to?
   Prompts:
   How many lectures were you expected to go to?
   How often were you expected to attend a lab session?
   Do you prefer working in a group or individual setting?
   Approximately how many people were in lectures? What about in the labs?
   What did you most enjoy in your first year? Prompt - Why?
   What did you enjoy the least? Prompt - Why?

4. I would like to get a clearer picture of the things how your feelings about physics have changed since you began your degree. Thinking about where you are now, is there part of your degree that you look forward to more than others?
   Prompts:
   Do you get a lot of opportunity to do this?
   Do you think your expectations about your degree have changed since your first year?
   Have you chosen to do anything that you might not have thought about in your first year?
   Have you done or chosen anything that might have surprised your younger self?

5. I want to get an idea of the most memorable parts of your degree course; unforgettable moments things that have happened since you started. Have there been any moments or experiences during the times you are 'doing physics' here that stick in your mind; the sort of thing you might tell younger relatives about when you are older?
   Prompts:

Has there been any significant person you can remember saying or doing anything special?

What about lab sessions; have there been any experiments that have just made your day, or equally gone disastrously wrong?

Have you had any discussions during tutorials that have had any impact on your thinking?

Have there been any moments when your work has been highlighted or recognised?

Have you ever got into trouble about your work or behaviour?

Have there been any events off campus that have influenced your work here?

6. I am now going to ask you some questions about what you see yourself doing in the future. Have you thought about what your next steps will be?
   Prompt:
   Can you tell me more about that?
   Is there anything in particular that has influenced you in that decision?

7. Have you thought about what you might be doing in ten years' time in terms of your career? Prompts:
   How old will you be?
   Do you think you will be living in this area still?
   What needs to happen to make your dreams possible?
   What kinds of things might stop you?
   Can you tell me how you feel about that?
   Can you tell me more about ...?
   How do you mean? In what way?
   You said earlier that ...Can we talk a bit more about that?

8. Do you think that your future ambitions or career expectations have changed because of your time here?
   Prompts:
   What do you think may have happened over your time here to influence your decision?
   Can you think of anything specific that has happened?
   What do you feel about these changes?

During our interview, we have discussed events, people and places that have had influence over your decision to take this degree; is there anything else you would like to add to your timeline at this point?

Well that completes the interview. Thanks very much for taking the time to talk to me. I just want to remind you that everything you have talked about will remain confidential and you will remain entirely anonymous. When I have transcribed the interview, I will email you so that you can read through it and amend it if you feel it necessary.

Turn recorder off.

Everything you have talked about will be really helpful in my analysis of how people experience physics degrees in different universities.

EWB: I understand that you've talked about things that have made you feel quite uncomfortable in this interview. I just wanted to make sure you were alright – if you feel you need more support, then this has the contact details for Student Support Services [Provide cards with relevant support details].

Interview code	
Length	
Date	
Place	
Interview environment	Private, Quiet, Interrupted, Noisy, Distractions, Other
General attitude	Friendly, cooperative but not particularly friendly indifferent and bored, nervous & uneasy suspicious or hostile, other
Feelings through body language or non-verbal actions, hand movements or facial expressions	If yes, give question number & describe
Was respondent suspicious, hostile, nervous or uneasy at any particular parts of interview?	If yes, give question number & describe

APPENDIX G SCIENCE CURRICULUM COMPARISON TABLES

Table 4: Scientific processes - Lower secondary level (Department for Education, 2012b)

Aspect of scientific enquiry	**England (1999) Y7-9**	**England (2007) Y7-9**	**Hong Kong (1999) Y7-9**	**Massachusetts (2006) Y7-9**	**Singapore (2001) Y8-9**	**Victoria (2008) Y8-9**
Science is about generating explanation that is supported by evidence Scientists ask questions that can be answered through carrying out investigations	Interplay between empirical questions, evidence and scientific explanation. Importance of testing explanations by using them to make predictions and collecting evidence. How scientists (have) work(ed).	Scientific thinking as a concept: - using scientific ideas to explain phenomena, generate and test theories; and - critically analysing and evaluating evidence from investigations.	What is science? The work of a scientist; Realising the limitations of scientific knowledge.		Scepticism for generalisations not based on verifiable observation. Recognise products of science are tested data collected over a long time, and explain how scientists have formulated concepts, principles and theories.	Nature of scientific thinking is not static. Expand pupils' knowledge to include abstract concepts, theories, principles and models drawn from traditional and emerging sciences.
Participate in designing and carrying out investigations – decide on the questions to be investigated	Turn ideas into a form that can be investigated and decide on appropriate approach; choose data sources; carry our preliminary work and make predictions.	Use scientific methods and techniques to develop and test ideas/ explanations.	Identifying the problem to be investigated; identifying factors involved; and proposing a hypothesis.	Formulate a testable hypothesis.	Define problem/ask question that can be verified by experiment; suggest possible hypothesis (tentative explanation); make a verifiable prediction based on known data	
Participate in designing and carrying out investigations – design the investigation	Consider key factors that need to be taken into account, including contexts in which variables can't be controlled; decide extent and range of data to collect and techniques, equipment and materials to use.	Plan practical/ investigative activities.	Design an investigation.	Design and conduct an experiment specifying variables to be changed, controlled and measured; control variables to ensure a fair test.	Determine variables to be measured and controlled; design simple experiments.	Justify selection of equipment and procedures, etc. Controlled studies using appropriate experimental tools. Basic sampling procedures in fieldwork.
Participate in designing and carrying out investigations – carry out the investigation, including correct use of equipment and taking and	Use range of equipment and materials appropriately. Make observations and measurements to appropriate degree of	Carry out practical/ investigative activities.	Proper handling of simple apparatus. Observing and recording the results.	Select appropriate tools and technology. Make quantitative observations and carry out several measurements	Acquire and use scientific practical skills; make careful observations and repeated measurements.	Technical uses of a range of instruments and chemicals and procedures. Develop skills in measuring. Use standard laboratory

recording measurements	precision, and sufficient to reduce error and obtain reliable evidence.			to minimize sources of error.		instruments and equipment and methods. Make systematic observations.
Have regard to health and safety when carrying out investigations	Use equipment and materials appropriately and take action to control risks to themselves and others. Recognise that there are hazards an assess risks and take action.	Assess risk and work safely.	Laboratory safety rules; safety measures to be observed; coping with common laboratory accidents.	Safe laboratory practices.	Observe laboratory rules at all times.	Practice safe, responsible and ethical behaviour when conducting investigations.
Interpret the findings of investigations and communicate their conclusions	Use diagrams, charts and graphs to show data; use observations, measurements and data to draw conclusions; decide to what extent conclusions support a prediction; use scientific knowledge to explain and interpret; consider	Obtain, record and analyse data; use findings to provide evidence for scientific explanations.	Interpreting data; drawing conclusions.	Present and explain data. Draw conclusions based on data and make inferences.	Describe trends in data, even when patterns are not exact; infer from data. Advance an explanation and state limits within which it holds.	Present data. Use a range of tools to explain and interpret observations. Justify conclusions drawn against prediction or hypothesis investigated. Prepare and present reports using appropriate diagrams and symbols.

APPENDIX H IOP DEFINITION OF PHYSICS BASED SECTORS **(Institute of Physics, 2012)**

Class	**Description**	**Class**	**Description**
6.10	Extraction of crude petroleum	30.20	Manufacture of railway locomotives and rolling stock
06.20	Extraction of natural gas	30.30	Manufacture of air and spacecraft and related machinery
09.10	Support activities for petroleum and natural gas extraction	30.40	Manufacture of military fighting vehicles
20.13	Manufacture of inorganic basic chemicals	30.91	Manufacture of motorcycles
21.20	Manufacture of pharmaceutical preparations	32.50	Manufacture of medical and dental instruments and supplies
23.44	Manufacture of other technical ceramic products	33.11	Repair of fabricated metal products
24.46	Processing of nuclear fuel	33.12	Repair of machinery
25.40	Manufacture of weapons and ammunition	33.13	Repair of electronic and optical equipment
25.99	Manufacture of other fabricated metal products n.e.c.	33.14	Repair of electrical equipment
26.11	Manufacture of electronic components	33.15	Repair and maintenance of ships and boats
26.12	Manufacture of loaded electronic boards	33.17	Repair and maintenance of transport equipment n.e.c.
26.20	Manufacture of computers and peripheral equipment	33.20	Installation of industrial machinery and equipment
26.30	Manufacture of communication equipment	35.11	Production of electricity
26.40	Manufacture of consumer electronics	35.12	Transmission of electricity
26.51	Manufacture of instruments and appliances for measuring, testing and navigation	35.13	Distribution of electricity 26.60 Manufacture of irradiation, electromedical and electrotherapeutic equipment
8.12	Collection of hazardous waste	26.70	Manufacture of optical instruments and photographic equipment
38.22	Treatment and disposal of hazardous waste	26.80	Manufacture of magnetic and optical media
43.22	Plumbing, heat and air-conditioning installation	27.11	Manufacture of electric motors, generators and transformers
51.22	Space transport	27.12	Manufacture of electricity distribution and control apparatus
52.21	Service activities incidental to land transportation	27.20	Manufacture of batteries and accumulators
52.22	Service activities incidental to water transportation	27.31	Manufacture of fibre-optic cables
52.23	Service activities incidental to air transportation	27.32	Manufacture of other electronic and electric wires and cables
60.10	Radio broadcasting	27.33	Manufacture of wiring devices
61.10	Wired telecommunications activities	27.40	Manufacture of electric lighting equipment
61.20	Wireless telecommunications activities	27.51	Manufacture of electric domestic appliances
61.30	Satellite telecommunications activities	27.90	Manufacture of other electrical equipment
61.90	Other telecommunications activities	28.11	Manufacture of engines and turbines, except aircraft, vehicle and cycle engines

62.09	Other information technology and computer service activities	28.21	Manufacture of ovens, furnaces and furnace burners
71.11	Architectural activities	28.23	Manufacture of office machinery and equipment (except computers and peripheral equipment)
71.12	Engineering activities and related technical consultancy	28.25	Manufacture of non-domestic cooling and ventilation equipment
71.20	Technical testing and analysis	28.29	Manufacture of other general-purpose machinery n.e.c.
72.11	Research and experimental development on biotechnology	28.49	Manufacture of other machine tools
72.19	Other research and experimental development on natural sciences and engineering 28.99		Manufacture of other special-purpose machinery n.e.c.
74.20	Photographic activities	29.10	Manufacture of motor vehicles
74.90	Other professional, scientific and technical activities n.e.c.	29.31	Manufacture of electrical and electronic equipment for motor vehicles
84.22	Defence activities	30.11	Building of ships and floating structures
95.12	Repair of communication equipment		

END NOTES

[i] JACS 3 Classification of Physics
F310 Applied physics: Topics in physics of commercial or social importance.
F311 Engineering physics: Physical principles and techniques applied to engineering and technology.
F320 Chemical physics: Concerned with central area of physical science, integrating chemistry and physics.
F321 Solid-state physics: Study of the structure of solids and the explanation of their properties.
F330 Environmental physics: Aspects of physics concerned with environmental issues.
F 331 Atmospheric physics: The study of the Earth's stratosphere, troposphere and upper atmosphere including atmospheric kinetics and water in the atmosphere.
F332 Marine physics: The study of the physical properties of the marine environment.
F340 Mathematical & theoretical physics: The mathematical principles and techniques of physics theory and explanation of physical phenomena.
F341 Electromagnetism: The study of the interaction of charges in electromagnetic fields.
F342 Quantum mechanics: Description and analysis of sub-atomic behaviour.
F343 Computational physics: Numerical and quantitative methods in physics.
F350 Medical physics: The application of Physics to the medical sciences.
F351 Radiation physics: Monitoring and evaluation of emissions from sources of radiation.
F360 Optical physics: The study of optics as a natural phenomenon and optical instrumentation.
F361 Laser physics: The study of lasers as optical instrumentation.
F370 Nuclear & particle physics: The study of matter at atomic and sub-atomic level, and of the structure and behaviour of nuclei.
F380 Acoustics: The study of the propagation and transmission of sound waves.
F390 Physics not elsewhere classified: Miscellaneous grouping for related subjects, which do not fit into the other Physics categories. To be used sparingly.